ASSESSMENT REPORT ON

PROPYLENE OXIDE

FOR DEVELOPING AN AMBIENT AIR QUALITY GUIDELINE

104-02453/

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Prepared for
Alberta Environment

By
WBK & Associates Inc.

March 2002

Pub. No: T/658
ISBN No. 0-7785-2114-1 (Printed Edition)
ISBN No. 0-7785-2115-X (On-line Edition)
Web Site: http://www3.gov.ab.ca/env/protenf/standards/index.html

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FOREWORD

Alberta Environment maintains Ambient Air Quality Guidelines to support air quality management in Alberta. Alberta Environment currently has ambient guidelines for thirty-one substances and five related parameters. These guidelines are periodically updated and new guidelines are developed as required. Fact Sheets on Ambient Air Quality Guidelines were updated in September 1997 and February 2000.

With the assistance of the Clean Air Strategic Alliance, a multi-stakeholder workshop was held in October 2000 to set Alberta's priorities for the next three years. Based on those recommendations, a three-year work plan ending March 31, 2004 was developed to review four existing guidelines, create three new guidelines for three families of substances, and adopt six new guidelines from other jurisdictions.

This document is one in a series of documents that presents the scientific assessment for these substances.

Lawrence Cheng, Ph.D.
Project Manager
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SUMMARY

Propylene oxide is a colourless, highly volatile liquid. It does not occur naturally; however, it may be formed in the photochemical smog cycle. Propylene oxide is typically used as a starting material in the production of polymers, oxygenated solvents and industrial fluids. The only industrial sector contributing to propylene oxide emissions in Canada is the chemical and chemical products industries. In this sector, the major contributors are industrial organic chemicals manufacturing industries, plastic and synthetic resin industries, and soap and cleaning compounds industries. The National Pollutant Release Inventory reports that there are no major emissions of propylene oxide from industrial facilities in Alberta.

No published literature could be found on the effects of propylene oxide on terrestrial vegetation, although structural derivatives of this compound have been used as herbicides. The primary route of propylene oxide exposure in humans would be through inhalation, although there may be some exposure through residues in food after sterilization and fumigation. It is unlikely that significant exposure to propylene oxide would occur in the absence of an industrial source or hazardous waste facility emitting this substance.

The literature reports that acute (short-term) exposure of animals to propylene oxide causes a number of adverse responses. These include tearing of the eyes, salivation, respiratory irritation (lung, nasal passages), vomiting, central nervous system depression, and death. These types of responses have been observed in controlled animal studies at concentrations ranging from 48 to 38,000 mg/m^3 (20 to 16,000 ppm) over exposure durations ranging from 30 minutes to 7 hours.

Propylene oxide has been shown to be a direct acting carcinogen, producing tumours at the site of exposure (in the nasal cavity) in rats and mice intermittently exposed propylene oxide at concentrations greater than 950 mg/m^3 (400 ppm) for 103 weeks. Reports of chronic exposures in humans are occupational and usually associated with multiple chemical exposure, including ethylene oxide. Ethylene oxide and propylene oxide have similar reaction kinetics; however, propylene oxide's mutagenic and genotoxic potential is much lower. Ethylene oxide has been demonstrated to be a human carcinogen and a more potent rodent carcinogen. As a result of this and the carcinogenic potential in animals, propylene oxide is normally treated as a potential carcinogen in humans by most agencies regulating its use in the environment.

Non-cancer responses reported to occur during chronic-exposure animals studies associated with inhalation of propylene oxide include decreased growth rate, nasal epithelium inflammation, irritation of respiratory passages, lung and nerve damage, ovarian and testicular degeneration, skeletal muscle degeneration, mild developmental effects, and death. These types of responses have been observed at exposure concentrations ranging from 70 to 3,400 mg/m^3 (30 to 1,440 ppm).

The majority of agencies reviewed as part of this assessment do not have an air quality guideline for acute exposure conditions. Exceptions to this are a 1-hour guideline of 3,100 $\mu g/m^3$ (1,300 ppb) adopted by the California Environmental Protection Agency based on nasal irritation in mice and a 1-hour guideline of 210 $\mu g/m^3$ (88 ppb) adopted by the Texas Natural Resources Conservation Commission (basis unknown). The province of Ontario uses a maximum point of

impingement guideline of 450 $\mu g/m^3$ (190 ppb) for a 30-minute averaging time. Several state agencies use a 24-hour guideline for specific purposes, with values ranging from 30 to 1,140 $\mu g/m^3$ (13 to 480 ppb). These states include Michigan, New Hampshire, Rhode Island, and Wisconsin. The origin for some of these guidelines is from occupational exposure limits, while for others it is unknown.

Almost all of the agencies have chronic, long-term (>1 year) guidelines for propylene oxide based on carcer and/or non-carcer endpoints. A number of agencies use the US Environmental Protection Agency's inhalation unit cancer risk factor of 3.7E-06 per $\mu g/m^3$. Using this unit risk factor and an increased lifetime cancer risk of 1 in 100,000 (a risk criterion commonly used in Alberta), an air concentration of 3 $\mu g/m^3$ (1.3 ppb) is estimated for propylene oxide. This corresponds to the guideline level for cancer used by most of these agencies. Some of the agencies use a non-cancer endpoint developed by the US Environmental Protection Agency (reference concentration of 30 $\mu g/m^3$ or 13 ppb) as an additional chronic air guideline.

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ACKNOWLEDGEMENTS

The authors of this report would like to thank Dr. Lawrence Cheng of Alberta Environment for inviting them to submit this assessment report. The authors are grateful for the help and guidance provided by Dr. Cheng and his colleagues at Alberta Environment.

WBK & Associates Inc. would also like to acknowledge the authors who participated in the completion of this report:

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1.0 INTRODUCTION

Alberta Environment (AENV) establishes Ambient Air Quality Guidelines under Section 14 of the Environmental Protection and Enhancement Act (EPEA). These guidelines are part of the Alberta air quality management system (AENV, 2000).

The main objective of this assessment report is to provide a review of scientific and technical information to assist in evaluating the basis and background for an Ambient Air Quality Guideline for propylene oxide. The following aspects were examined as part of the review:

- physical and chemical properties,
- existing and potential natural and anthropogenic emissions sources in Alberta,
- effects on humans, animals, and vegetation,
- monitoring techniques,
- ambient air guidelines in other Canadian jurisdictions, United States, European Union and Australia, and the basis for development and use.

Important physical and chemical properties that govern the behaviour of propylene oxide in the environment include, but are not limited to, chemical structure, molecular weight, melting and boiling points, water solubility, density, vapor density, organic carbon partition coefficient, octanol water partition coefficient, vapor pressure, Henry's Law constant, bioconcentration factor, and odor threshold. Values for these properties will be reviewed and presented in this report.

Existing and potential natural and anthropogenic sources of propylene oxide emissions in Alberta will also be presented. Natural emissions of propylene oxide are described in the literature. Anthropogenic emissions are provided in Environment Canada's National Pollutant Release Inventory (NPRI).

Scientific information about the effects of propylene oxide on humans and animals is reported in published literature and other sources. This information includes toxicological studies published in professional journals and reviews and information available through the International Agency for Research on Cancer (IARC), and US Environmental Protection Agency's Integrated Risk Information System (IRIS). These sources provide valuable information for understanding health effects of propylene oxide exposure.

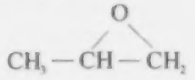
Reference air monitoring and other techniques for detecting propylene oxide in air are also documented in published literature. Several widely used and accepted reference methods exist for propylene oxide. These methods have been developed, tested and reported by US Environmental Protection Agency (US EPA), US National Institute of Occupational Safety and Health (NIOSH), and US Occupational Safety and Health Administration (OSHA).

2.0 GENERAL SUBSTANCE INFORMATION

Propylene oxide is a colourless, highly volatile liquid at ambient temperature and pressure (IPCS, 1985). Its odour has been described as sweet (Verschueren, 2001; Ontario MOE, 2001), ethereal (Ontario MOE, 2001; Lewis, 1993; IPCS, 1988; 1985), alcoholic (Ontario MOE, 2001) and neutral to pleasant (Verschueren, 2001). Propylene oxide vapours form an explosive mixture with air (Lewis, 2000; IPCS, 1988; 1985). When heated, decomposition of propylene oxide emits acrid smoke and irritating vapours (Lewis, 2000). Exposure of propylene oxide to epoxy resin and sodium hydroxide also leads to explosive reactions (Lewis, 2000). Propylene oxide can react violently with oxidizing materials (Lewis, 2000; IPCS, 1988; 1985), chlorine, ammonia and acids (IPCS, 1988; 1985). Reactions of propylene oxide with water, alcohols, amines, halides and sulfhydryl compounds leads to ring opening (IPCS, 1985).

Table 2-1 provides a list of common synonyms, trade names and a list of important identification numbers for propylene oxide. Propylene oxide is a flammable liquid (Lewis, 2000).

Table 2-1 Identification of Propylene Oxide

Property	Value
Formula	C_3H_6O
Structure	
CAS Registry number	75-56-9
RTECS number	TZ2975000
UN Number	UN1280
Common Synonyms	Epoxy propane 1,2-epoxypropane 2,3-epoxypropane Methyl ethylene oxide Methyl oxirane methyloxacyclopropane Propene oxide 1,2-propylene oxide propylene epoxide
Tradenames	AD6 AI3-07541 EPA Pesticide Chemical Code 042501 Caswell No. 713A

Propylene oxide is typically used as a starting material in the production of polymers (polyurethanes and polyesters), oxygenated solvents and industrial fluids (Kahlich et al., 2001). Propylene oxide is used primarily to produce chemicals such as polyether polyols, propylene glycol, polypropylene glycol, dipropylene glycol, glycol ethers, glycerin and surfactants (IPCS, 1985), with polyether polyols and propylene glycol being the two most important applications (Kahlich et al., 2001). In 1982, of the propylene oxide manufactured in Canada, 42% was used for polyol production, 19% for propylene glycol production and 35% was exported (EC, 1985). Propylene oxide has also been used for sterilization of medical equipment and fumigation of foodstuffs (IPCS, 1988; 1985).

2.1 Physical, Chemical and Biological Properties

The physical and chemical properties of propylene oxide are summarized in Table 2-2.

2.2 Environmental Fate

The environmental fate of propylene oxide is summarized in Table 2-3. Due to its high vapour pressure and its tendency to hydrolyze, propylene oxide does not persist in soil or water (Howard, 1989; EC, 1985). The suggested values for the organic carbon partition coefficient and bioconcentration factor also indicate that partitioning to soil or sediment or bioaccumulation will be negligible. If propylene oxide is released to the atmosphere, it will react photochemically with hydroxyl radicals. Due to its relatively high water solubility, propylene oxide may be removed from air by rainfall (Ontario MOE, 2000).

Table 2-2 Physical and Chemical Properties of Propylene Oxide

Property	Value	Reference
Molecular Weight	58 08	Lide, 2001
Physical state	Liquid	Lide, 2001
Melting Point	-111.9 °C	Lide, 2001
	-104.4 °C	Verschueren, 2001; IPCS, 1985
	-112.13 °C	Ontario MOE, 2001; Genium, 1999; Howard, 1989; IPCS, 1988
Boiling Point	35 °C	Verschueren, 2001; Lide, 2001
	33 9 °C	Lewis, 2000, Lewis, 1993
	34 23 °C	Ontario MOE, 2001, Howard, 1989, IPCS, 1985
	37 8 °C	IPCS, 1988
Specific gravity (liquid)	0 859 at 0 °C	Verschueren, 2001, Lide, 2001
	0 8304 at 20 °C	Ontario MOE, 2001; Lewis, 2000; Lewis, 1993, IPCS, 1985
Specific gravity (gas) (air =1)	2	Genium, 1999, IPCS, 1988, 1985
Vapour pressure	59 kPa at 20 °C	Ontario MOE, 2001, Genium, 1999, Lewis, 1993, IPCS, 1988; 1985
	53 kPa at 17 8 °C	Verschueren, 2001; Lewis, 2000
	71kPa at 25 °C	Howard, 1989
Solubility in water	405 g/L at 20 °C	Verschueren, 2001, Genium, 1999; IPCS, 1985; EC, 1985
	476,000 mg/kg	Howard, 1989, Ontario MOE, 2001; ATSDR, 1990
Solubility	Soluble in alcohol and ether	Genium, 1999; Lewis, 1993
	Miscible with most organic solvents	Genium, 1999
Henry's Law Constant	8.3×10^{-5} atm m^3/mol	Genium, 1999
	$8\ 54 \times 10^{-5}$ atm m^3/mol	Howard, 1989
Octanol water partition coefficient (log K_{ow})	0 08	Verschueren, 2001
	0 03	Lide, 2001, Genium 1999, Howard, 1989
	-0 13	IPCS, 1988, 1985
Organic carbon partition coefficient (Log K_{oc})	3 6	Genium, 1999
	4 2, 30	Howard, 1989
Flash Point (closed cup)	-37 °C	Lide, 2001, IPCS, 1988, 1985
	-37 2 °C	Genium, 1999, Lewis, 1993
	-19 44 °C	Ontario MOE, 2001
Explosive limits	3 1% to 27 5%	Lide, 2001
	2 3% to 36%	Genium, 1999
	2% to 22%	Lewis, 1993
	2% to 37%	IPCS, 1988, 1985
Autoignition temperature	449 °C	Lide, 2001; Genium, 1999
Odour threshold	9 9 ppm (absolute perception) to 35 ppm (100% recognition)	Verschueren, 2001
	80 to 470 mg/m^3 (recognition) 1125 mg/m^3 (irritation)	Ontario MOE, 2001
	24 7500 to 500 000 mg/m^3	Genium, 1999
	20 mg/m^3 (perception) and 80 to 470 mg/m^3 (recognition)	IPCS, 1988; 1985
	10 to 2000 ppm	EC, 1985
Bioconcentration factor in fish	no food chain concentration potential	Genium, 1999
	-0 2 and –0.4	Howard, 1989
Conversion factors for vapour (at 25 °C and 101.3 kPa)	1 ppm = 2 37 mg/m^3	Verschueren, 2001; IPCS, 1988, 1985
	1 mg/m^3 = 0 421 ppm	Verschueren, 2001; IPCS, 1988

Table 2-3 Environmental Fate of Propylene Oxide (based on Verschueren, 2001; Toxnet, 2001; Genium, 1999; IARC, 1994; Howard, 1989)

System	Fate	Half life
Water	Hydrolysis with formation of propylene glycol; hydrolysis is accelerated by the presence of chloride ions (reaction with chloride produces 1-chloro-2-propanol and 2-chloro-1-propanol), loss by volatilization; adsorption to sediment or suspended particulate matter, bioconcentration in aquatic organisms and reactions with hydroxyl radicals in water are negligible	• *Hydrolysis*: 11.6 days (pH=7-9) and 6.6 days (pH=5); 4.5 days (pH=7-9) and 1.5 days (pH=5) • *Volatilization*: = 3 to 18 days
Soil	Rapid volatilization from dry soils; significant hydrolysis and some volatilization from moist soils; negligible adsorption to soil; high mobility in soil; potential for leaching	
Air	Degradation by reaction with hydroxyl radicals; no significant reaction with ozone; photooxidation may lead to the formation of acetylformyloxide, formaldehyde, formandehyde and methylglyoxan; physical removal is negligible; some removal by rainfall	• *Photochemical reactions with hydroxyl radicals*: 14 to 31 days • *Atmospheric half life*: 3 to 20 days

3.0 EMISSION SOURCES AND INVENTORIES

3.1 Natural Sources

Propylene oxide does not occur naturally (Ontario MOE, 2001; Howard, 1989; IPCS, 1985); however, it may be formed in the photochemical smog cycle (Ontario MOE, 2001).

3.2 Anthropogenic Sources

3.2.1 Industrial

Tables 3-1 and 3-2 provide total propylene oxide emissions and propylene oxide emissions to air, as reported in the 1999 National Pollutant Release Inventory (NPRI, 1999). According to the NPRI (NPRI, 1999), the only industrial sector contributing to propylene oxide emissions is the chemical and chemical products industries. In this sector, the significant contributors are the industrial organic chemicals manufacturing industries, the plastic and synthetic resin industries and the soap and cleaning compounds industries.

Of the total propylene oxide emissions, 100% is released to the air. Most of the propylene oxide released to the air is the result of evaporation or vented gases during production, handling, storage, transportation and use (Ontario MOE, 2001; IPCS, 1985).

Tables 3-1 and 3-2 indicate that, according to the NPRI database (NPRI, 1999), there are no facilities in Alberta reporting emissions of propylene oxide. It should be noted; however, that a facility is only required to report to the NPRI if it meets all three of the following criteria (NPRI, 1999):

- the facility has more than 10 full-time employees,
- the facility manufactured, processed or used 10 tonnes or more of an NPRI substance in the calendar year,
- the facility manufactured, processed or used an NPRI substance at a concentration greater than or equal to 1% by weight.

It may be possible that propylene oxide is emitted in Alberta in such small amounts that the facilities are not required to report to NPRI. Based on the uses reported for propylene oxide in the previous section, it is unlikely that emissions occur from sectors not reporting to NPRI.

3.2.2 Other

Other sources of propylene oxide include automobile exhaust and exhausts of other hydrocarbon-burning stationary sources (Ontario MOE, 2001).

Table 3-1 Total Emissions of Propylene Oxide According to NPRI, 1999 (in tonnes)

NPRI ID	Company	City	Province	Propylene Oxide Emissions (tonnes)				
				Air	Water	Land	Underground	Total
3146	Dow Chemical Canada Inc.	Sarnia	ON	6.640	0	0	0	6.640
0800	Rhodia Canada Inc.	Mississauga	ON	3.453	0	0	0	3.453
1436	Huntsman Corporation Canada Inc.	Guelph	ON	0.310	0	0	0	0.310
				10.403	0	0	0	10.403

Table 3-2 Air Emissions of Propylene Oxide According to NPRI, 1999 (in tonnes)

NPRI ID	Company	City	Province	Air Emissions of Propylene Oxide (tonnes)					
				Stack /Point	Storage /Handling	Fugitive	Spills	Other Non-Point	Total
3146	Dow Chemical Canada Inc.	Sarnia	ON	6.305	0.059	0.276	0	0	6.640
0800	Rhodia Canada Inc.	Mississauga	ON	0.253	0	3.200	0	0	3.453
1436	Huntsman Corporation Canada Inc.	Guelph	ON	0.060	0	0.250	0	0	0.310
				6.618	0.059	3.726	0	0	10.403

4.0 EFFECTS ON HUMANS AND ECOLOGICAL RECEPTORS

4.1 Humans and Animals

The focus of the information discussed is on exposures to propylene oxide via inhalation. The primary route of exposure to propylene oxide is via inhalation from an industrial air source, although, there may be some exposure through residues in food after sterilization and fumigation. Once inhaled, it is readily absorbed and rapidly metabolized (IARC, 1994; IPCS, 1985; 1988).

Propylene oxide is mutagenic in bacteria and in numerous *in vitro* and *in vivo* studies of animal and human cells (Vogel and Nivard, 1998; Farooqi et al., 1993; Agurell et al., 1991; Högstedt et al., 1990; Ehrenberg and Hussain, 1981; Hussain, 1981). Propylene oxide directly alkylates macromolecules including haemoglobin and DNA in experimental animals and humans (Ríos-Blanco et al., 1997; IARC, 1994; Farooqi et al., 1993).

In animal studies, propylene oxide is a direct acting carcinogen producing tumours at the sites of exposure. However, studies of human exposure do not conclusively describe propylene oxide as a carcinogen (IARC, 1994; IPCS, 1985; 1988).

4.1.1 Overview of Chemical Disposition

No human *in vivo* toxicokinetic information was available. In experimental animal systems, propylene oxide is rapidly absorbed, distributed to the body tissues and metabolized (Svensson et al., 1991; Golka et al., 1989; Arms and Travis, 1988; Segerbäck 1983). Metabolism occurs primarily by glutathione epoxide transferase and results in the detoxification of the chemical; high exposure doses may saturate this pathway resulting in tumour development (Ríos-Blanco et al., 1997; Couch et al., 1996; IARC, 1994; IPCS 1985; 1988). Metabolism also occurs via epoxide hydrolase producing 1,2-propanediol, then lactic and pyruvic acids (IARC, 1994).

Propylene oxide directly alkylates macromolecules including haemoglobin and DNA in experimental animals and in humans (Ríos-Blanco et al., 1997; IARC, 1994; Segerbäck et al., 1994; Farooqi et al., 1993; Högstedt et al., 1990). Segerbäck et al. (1994) reported a dose-dependent increase in adducts in many body tissues (blood, brain, lung, liver) of rats, mice and dogs after inhalation or injection of propylene oxide. Distribution of the adduct varied with route of exposure. The human exposure dose for propylene oxide was estimated after occupational exposures through measurement of haemoglobin adducts in workers (Boogaard et al., 1999; IARC, 1994; Kautiainen and Törnqvist, 1991; Högstedt et al., 1990; Törnqvist and Ehrenburg, 1990; Pero et al., 1985).

4.1.2 Genotoxicity and Mutagenicity

Propylene oxide is a reactive alkylating agent, its mutagenicity has been demonstrated in microorganisms and insects (Vogel and Nivard, 1998; Hussain, 1981). Propylene oxide also is genotoxic in mammalian cells producing DNA damage, mutations, and chromosomal aberrations (*in vitro*) (Haseman and Hailey, 1997; Ríos-Blanco et al., 1997; IPCS, 1985; 1988; Sina et al., 1983; Bootman et al., 1979; Dean and Hodson-Walker, 1979). The frequency of DNA alkylation in nasal respiratory tissue (target tissue) was greater than in other non-target tissues (nasal

olfactory, hepatic, and testicular tissues) after inhalation of propylene oxide. The distribution of DNA adducts varies with route of exposure (Ríos-Blanco et al., 2000).

Inhalation of propylene oxide did not produce chromosomal aberrations or sister chromatid exchanges in monkeys (Lynch et al., 1984b) or any dominant lethal effects in rats (Hardin et al., 1983a; Bootman et al., 1979). Clastogenic effects were reported in humans at 325 ppm (770 mg/m^3) (Vogel and Nivard, 1998).

Chromosomal aberrations were significantly increased in workers exposed to alkene oxides (including propylene oxide) for greater than 20 years. No increase in chromosomal aberrations was reported in workers exposed up to 17.6 years. However, due to the number of different chemicals workers are exposed to in chemical plants, effects specifically associated with propylene oxide could not be determined (Thiess et al., 1981a,b). Examination of a group of workers exposed to relatively low concentrations (0.33-11.4 ppm (0.78-27 mg/m^3) (Högstedt et al., 1990) and 0.6-12 ppm (1.4-28 mg/m^3) (Pero et al., 1982) reveled clastogenic effects (micronuclei and chromosomal breaks in lymphocytes) and reduction of unscheduled DNA synthesis (Pero et al., 1982; 1985).

4.1.3 Acute Effects

4.1.3.1 Acute Adverse Effects in Experimental Animals

Acute exposures to propylene oxide results in lacrymation, salivation, respiratory irritation (lung, nasal passages), vomiting, central nervous system (CNS) depression, and death. Table 4-1 lists some examples of NOAELs (No Observable Adverse Effects Level) and LOAELs (Lowest Observable Adverse Effects Level) for acute exposures reported in the literature.

4.1.3.2 Acute Adverse Health Effects In Humans

Accidental acute exposure to propylene oxide solutions is reported to have a narcotic effect, cause corneal and conjunctival damage, and produce allergic contact dermatitis (Nilsson et al., 1991; Jensen, 1981; Ketal, 1979; McLauglin, 1946). No clastogenic effects were reported in employees exposed to a single exposure of up to 1900 ppm (4503 mg/m^3) alkene oxides during a plant breakdown (Thiess et al., 1981a).

4.1.4 Sub-Chronic Effects

4.1.4.1 Sub-Chronic Effects in Experimental Animals

There was no change in body weights and no pathological effects were observed in a US NTP (1984) study of rats (0, 110, 230, 460, 1150, 3410 mg/m^3) (0, 46, 97, 194, 485, 1439 ppm) and mice (0, 50, 110, 230, 460, 1150 mg/m^3) (0, 22, 46, 97, 194, 485 ppm) exposed to propylene oxide for two weeks. Rats in the high dose group (3400 mg/m^3 (1435 ppm)) suffered dyspnoea, gasping, decreased activity, irregular limb movements and diarrhoea. Mice displayed dyspnoea, gasping and decreased activity in the two highest does groups (460 and 1150 mg/m^3) (194 and 485 ppm).

Table 4-1 Examples of NOAELs and LOAELs Associated with Acute Exposures in Animal Species

Effects Reported	Exposure Period	Air Concentration mg/m^3 (ppm)[a]	Species	References[b]
LC_{50}; with laboured breathing and CNS depression.	4h	9,500 (4,008)	Rats	Jacobson et al., 1956
1% mortality level.		5,250 (2,215)		
100% mortality.		17,000 (7,173)		
LC_{50}; with laboured breathing and CNS depression.		4,100 (1,730)	Mice	
1% mortality level		900 (380)		
100% mortality.		17,000 (7,173)		
Lacrymation, salivation, nasal discharge and vomiting. LOAEL		3,230 (1,363)	Dogs	
Congestion in lungs and trachea oedema of pulmonary tissue, necrosis of bronchiolar epithelium NOAEL		4,750 (2,004)		
Congestion in lungs and trachea oedema of pulmonary tissue, necrosis of bronchiolar epithelium LOAEL		4,810 (2,030) & 5,880 (2,481)		
Death.		4,750 (2,004)		
Organ injury NOAELs	0.5h	9,480 (4,000)	Rats	Rowe et al., 1956
	2h	4,740 (2,000)		
	7h	2,370 (1,000)		
4 of 10 animals died.	4h	9,480 (4,000)		
100% mortality.	30min	38,000 (16,034)		
100% mortality.	7h	9,500 (4,008)		
Lung host defenses NOAEL	3h	48.2 (20)	Mice	Aranyi et al., 1986
CNS depression (increases with level and length of exposure)		Single high (unspecified dose)	Rats & Mice	Rowe et al., 1956

[a] Conversion factor: 1ppm=2.37 mg/m^3, air at 25°C and 101.3 kPa (760mmHg) (IPCS, 1985).
[b] Cited In: IPCS (1985).

Eldridge et al. (1995) reported a dose and time depended increase in toxicity after exposing rats to increasing concentrations of propylene oxide (24.7, 48.2, 120.5, 361.5, 1265 mg/m^3 for up to 4 weeks) (10, 20, 50, 152, 534 ppm), with no adverse health effects observed in the 120.5 mg/m^3 (50 ppm) group. The adverse effects (cytotoxicity and cell proliferation in the nasal epithelium) were reversible with complete recovery four weeks after cessation of exposure.

Exposure of 500 ppm (1185 mg/m^3) propylene oxide to rats for weeks produced DNA adducts in nasal respiratory epithelium, lung, liver and testis (in significantly decreased amounts respectively). Haemoglobin adducts were also reported (Ríos-Blanco et al., 2000).

Inhalation of 3615 mg/m^3 (1525 ppm) propylene oxide (6 hours/day, 5 days/week, for 7 weeks) resulted in ataxia in the hind legs of rats without muscular atrophy. A histological examination reveled a central-peripheral distal axonopathy (Ohnishi and Murai, 1993; Ohnishi et al., 1988).

4.1.5 Chronic Effects

The results of animal and human studies reporting the adverse health effects associated with chronic exposures to propylene oxide have been reviewed (IARC, 1994; US NTP, 1985; IPCS, 1988; 1985). Examples of the lowest and highest animal NOAELs (No Observable Adverse Effect Level) and LOAELs (Lowest Observable Adverse Effect Level) from these reports and other studies identified in the literature are reported in Table 4-2.

Few exposure doses for human exposure were available, therefore, few NOAEL's and LOAEL's were available. Section 4.1.5.2 and Table 4-3 below describes human effects associated with long-term exposures.

4.1.5.1 Chronic Effects in Experimental Animals

4.1.5.1.1 Non-Carcinogenic Effects

Significant non-carcinogenic effects reported to occur in association with inhalation of propylene oxide includes: decreased growth rates; inflammation and proliferation of the nasal epithelium; irritation of the respiratory passages; histological damage in the lung; nerve damage; ovarian and testicular atrophy; skeletal muscle atrophy; decreased growth rates; mild developmental effects (wavy ribs, decreased number of implantations); and, death (IARC, 1994; Kuper et al., 1988; Lynch et al., 1984a; IPCS, 1985; Reuzel and Kuper, 1984; US NTP, 1984;1985; Sprinz et al., 1982; Rowe et al., 1956). See Table 4-2 for exposure concentrations associated with each effect.

Rats exposed sub-chronically to 1500 ppm (3555 mg/m^3) propylene oxide demonstrated central and peripheral sensory axonopathy (effects hind limbs and gait) (Ohnishi and Murai, 1993). Setzer et al., (1996) reported no significant neurotoxicity in monkeys after chronic exposure to 100 or 300 ppm (237 or 711 mg/m^3) propylene oxide.

Table 4-2 Examples of NOAEL's and LOAEL's Associated with Chronic Exposures in Animals

Effects Reported	Air Concentration (ppm (mg/m^3)[a])	Species	Reference
No clinical signs NOAEL	100 (237)	Rats	Lynch et al., 1984a.
	302 (717)	Monkeys	Sprinz et al. 1982.
Gross or histopathological effects NOAELs	1 434 (3 400)	Rats	US NTP, 1984
	485 (1 150)	Mice	
Decrease body weight NOAEL	200 (474)	Rats&Mice	Renne et al., 1986.
		Mice	US NTP, 1985.
Decrease body weight LOAELs	100 (237)	Rats	Kuper et al , 1988; Lynch et al , 1984a
	300 (711)		Kuper et al., 1988.
		Rats&Mice	Renne et al., 1986.
	400 (948)	Mice	US NTP, 1985; 1984
General health, biochemistry, urinalysis, haemotology, gross histopathology NOAEL	300 (712)	Rats	Reuzel and Kuper, 1984
General health, biochemistry, urinalysis, haemotology, gross histopathology LOAEL	456 (1,080)	Rabbits and Monkeys	Rowe et al , 1956
Irritation of eyes and respiratory passages Histopathological changes in the lungs and nasal mucosa. LOAEL	200 (474)	Rats&Mice	US NTP, 1983.
	100 (237)	Rats	Lynch et al., 1984a.
	102 (242)		Reuzel and Kuper, 1984.
	200 (474)	Rats&Mice	Renne et al., 1986.
	100 (237)	Rats	Kuper et al., 1988.
Increased mortality rate NOAELs	456 (1080)	Guinea Pigs	Rowe et al., 1956.
	200 (474)	Mice	Renne et al , 1986
	400 (948)	Rats	
	400 (948)	Rats	US NTP, 1985.
	30 (71)	Female Rats	Kuper et al., 1988.
Increased mortality rate LOAELs	456 (1,080)	Rats & Guinea Pigs	Rowe et al., 1956.
	400 (948)	Mice	US NTP, 1985.
	100	Rats	Lynch et al., 1984a.
	400 (948)	Mice	Renne et al., 1986.
	100 (237)	Female Rats	Kuper et al , 1988
	300 (711)	Rats	
Neurological NOAEL (peripheral neuropathy)	300 (711)	Monkeys	Setzer et al , 1996
Neurological LOAEL(Lesions in the medulla oblongata of the brain and axonial dystrophy in the nucleus gracilis).	100 (237)		Sprinz et al 1982
Reproductive NOAELs (sperm head abnormalities)	304 (720)	Mice	Hardin et al., 1983a.
	302 (717)	Monkeys	Lynch et al., 1984c.
Reproductive NOAEL (reproductive function)	300 (711)	Rats	Hayes et al , 1988
Ovarian atrophy NOAEL LOAEL	198 (470) 397 (940)	Mice	US NTP, 1984
LOAEL (testicular atrophy)	198 (470)	Rats	
LOAEL (decreased rel. testis wt)	100 (237)	Rats	Lynch et al., 1984a.
Carcinogenic NOAEL (Nasal)	198 (470)	Rats	US NTP, 1984.
Carcinogenic NOAEL (Mammary)	102 (242)		Reuzel and Kuper, 1984.
	400 (948)	Rats&Mice	Renne et al., 1986.
Carcinogenic LOAELs (Nasal)	397 (940)	Rats	US NTP, 1984
		Mice	
	400 (948)		Renne et al., 1986.
	400 (948)	Rats	US NTP, 1985
		Mice	
Carcinogenic LOAELs (Mammary)	300 (711)	Rats	Lynch et al., 1984a.
	397 (940)	Rats (female)	US NTP, 1984.
Carcinogenic LOAELs (Adrenal)	100 (237)	Rats	Kuper et al., 1988.
	100(237)		Lynch et al., 1984a

[a] When study did not describe concentrations in mg/m^3 and/or ppm the following conversion factor and assumptions were used: 1ppm=2 37 mg/m^3, air at 25°C and 101 3 kPa (760mmHg) (IPCS, 1985)

Propylene oxide also appears to be mildly fetotoxic in rats, with no signs of teratogenicity (Harris et al., 1989; Hayes et al., 1988; Hardin et al., 1983b; Hackett et al., 1982). Rats exposed before and during pregnancy to 500 ppm (1185 mg/m^3) propylene oxide demonstrated some fetotoxicity (decreased number of corpus lutea implantations and live fetuses; increased resorptions; increased wavy ribs; decreased skeletal ossifications, and decreased fetal body weight and crown rump length) as well as decreased body weight and maternal weight gain teratogenic (Harris et al., 1989; Hardin et al., 1983b; Hackett et al., 1982). These effects, with the exception of decreased body weight gain, were not observed at 300 ppm (711 mg/m^3) (Hayes et al., 1988). Rats appear to be more sensitive than rabbits, the later species experiencing no fetotoxicity, only decreased body weight and maternal weight gain (Hardin et al., 1983b; Hackett et al., 1982).

4.1.5.1.2 Carcinogenic Effects

Propylene oxide, like other reactive epoxides, is a direct acting carcinogen (Weisburger and Williams (1975), producing tumours at the site of exposure (IARC, 1994; IPCS, 1985). Inhalation produces degenerative and hyperplasic changes in the nasal mucosa and subsequent nasal tumours in rats and mice (Haseman and Hailey, 1997; Kuper et al., 1988; Lynch et al., 1984a; US NTP, 1983; 1984; 1985; Renne et al., 1986). The nasal mucosa in rats appears to be more sensitive than in mice (Haseman and Hailey, 1997). US NTP (1985) reported some evidence of carcinogenicity in rats and clear evidence of carcinogenicity in mice at 400 ppm (inhalation).

Inhalation exposure also results in an increase in total number of malignant tumours; mammary tumors (benign and malignant in female rats only); and, adrenal pheochromocytomas (Lynch et al., 1984a; Kuper et al., 1988) in rodents.

4.1.5.2 Human Chronic Effects

Reports of human exposures are occupational and usually associated with multiple chemical exposure including ethylene oxide. Ethylene oxide and propylene oxide have similar reaction kinetics; however, propylene oxide's mutagenic and genotoxic potential is much lower. Ethylene oxide has also been demonstrated to be a human carcinogen and a more potent rodent carcinogen (Vogel and Nivard, 1998; Couch et al., 1996; Farooqi et al., 1993; Högstedt et al., 1990; Lynch et al., 1984a; Ehrenberg and Hussain, 1981). Due to problems associated with occupational exposure studies (e.g., exposures to multiple chemicals, inaccurate/unavailable exposure doses, healthy worker effects, and life style differences), most human studies cannot be reliable used to determine effects associated with a specific chemical.

4.1.5.2.1 Non-Carcinogenic Effects

No reproductive or prenatal effects were identified in humans (IARC, 1994).

Although other epoxides have produced neuropathies in humans, neurotoxic effects have not been reported in workers exposed to propylene oxide (Ohnishi and Murai, 1993).

Table 4-3 Examples of NOAEL's and LOAEL's Associated with Chronic Occupational Exposures in Humans

Effects Reported	Average Air Concentration ppm (mg/m^3)[a]	Reference
Haemoglobin Adducts LOAEL	<0.042 – 4.22 (<0.1-10)	Boogaard et al., 1999
Clastogenic Effects NOAEL	3[b] (7) (<20 years)	Thiess et al., 1981a
Clastogenic Effects LOAELs	3[b] (7) (>20 yrs) <12[b] (28) (2-20 yrs) 0.33-11.4 (0.78-27)	Thiess et al., 1981a Pero et al., 1982. Högstedt et al., 1990.
Mortality NOAEL	3[b] (7) (>20 years)	Thiess et al., 1981b

[a] When study did not describe concentrations in mg/m^3 and/or ppm the following conversion factor and assumptions were used: 1ppm=2.37 mg/m^3, air at 25°C and 101.3 kPa (760mmHg) (IPCS, 1985)
[b] Note, air concentrations were measured during recent operation; it is reasonable to assume that earlier concentrations were higher due to the technology capabilities of the time.

4.1.5.2.2 Carcinogenic Effects

A study of occupational exposures to alkene oxide (including propylene oxide) did not demonstrate significant increases in mortality or cancers rates (Thiess et al., 1981b). A mutagenicity study revealed significant increases in chromosomal aberration rate in workers exposed 20 years or more. No significant increase was found in workers from the same plant with less than 20 years exposure, or who experienced a high acute exposure during a plant accident (Thiess et al., 1981a). Pero et al., (1982) reported a reduced capacity for DNA synthesis in workers exposed to relatively low concentrations of propylene oxide.

A small group of workers exposed to ethylene oxide reported an increased incidence of leukemia (Högstedt et al., 1979a, b, c). These results seem to be confirmed by two studies of two different plants which report an increase in pancreatic and lymphopoietic cancer among chlorohydrin production workers who would have been exposed to ethylene oxide (Benson and Teta, 1993; Greenberg et al., 1990). In response to the Benson and Teta (1993) and Greenberg et al. (1990) studies, Olsen et al., (1997) examined workers for pancreatic and lymphopoietic cancers after occupational exposure to ethylene oxide and propylene oxide. No significant increases were identified; however, the latency period between exposure and the time of the study was shorter than the first two studies; a follow up study was suggested (Olsen et al., 1997).

It is important to note that exposure to other chemicals (including ethylene oxide) also occurred in many of the occupational studies. In addition, difficulties establishing an accurate exposure dose, differences in lifestyle, individual metabolic differences, and healthy worker effect can also significantly influence the outcome of epidemiological studies. Although there is limited evidence that ethylene oxide is a human carcinogen, there is no conclusive evidence for propylene oxide. However, given that exposure to propylene oxide has been shown to produce haemoglobin and DNA adducts in humans and is carcinogenic in the experimental animal species, it may be prudent to consider this chemical to be potentially carcinogenic (IARC, 1994; US EPA, 1994; Nilsson et al., 1991; IPCS 1985; 1988).

4.1.6 Summary

Inhalation of propylene oxide can result in significant adverse health effects both acutely and chronically. It is readily absorbed and rapidly metabolized. Propylene oxide is mutagenic and genotoxic in many bacterial and mammalian. It has been observed to directly alkylate macromolecules including haemoglobin and DNA *in vivo* in animals and humans.

In chronic animal studies, propylene oxide is a direct acting carcinogen producing tumours at the sites of exposure. However, studies of human exposure do not conclusively describe propylene oxide as a carcinogen (IARC, 1994; IPCS, 1985; 1988).

4.2 Vegetation

No published literature was located on the effects of propylene oxide *per se* on terrestrial vegetation, although as stated in the previous section, its structural derivatives have been used as herbicides.

5.0 AIR SAMPLING AND ANALYTICAL METHODS

5.1 Reference Methods

Air sampling and monitoring methods for propylene oxide used in practice by established agencies are reported. In general, standard air monitoring methods for propylene oxide are based on volumetric sampling, canister sampling or pump-and-tube sampling approaches. Widely employed and accepted referenced standard air monitoring methods and technologies for propylene oxide have been developed by the United States Environmental Protection Agency (US EPA), National Institute of Occupational Safety and Health (NIOSH), and Occupational Safety and Health Administration (OSHA). Refer to Table 5-1 for a description of individual method advantages and disadvantages.

5.1.1 US EPA Compendium Method TO-15A

The US EPA has developed a methodology suitable for sampling ambient air for trace-level concentrations of propylene oxide. US EPA Compendium Method TO-15A describes the determination of volatile organic compounds (VOCs) (including propylene oxide) in air collected in specially prepared canisters and analyzed by gas chromatography/mass spectrometry (GC/MS) (US EPA, 1999). The advantages of this method include: incorporates a multisorbent/dry purge technique or equivalent for water management thereby addressing a more extensive set of compounds, establishes method performance criteria for acceptance of data, provides enhanced provisions for quality control, and unique water management approach allows analysis for polar VOCs. Disadvantages of this method are it requires expensive analytical equipment and a high level of operator skill to perform.

In this method, the ambient atmosphere is sampled by introduction of 6 liters (L) of air into a specially prepared stainless steel canister (SUMMA or equivalent) over an appropriate time and rate. Both subatmospheric pressure and pressurized sampling modes make use of an initially evacuated canister. A pump ventilated sampling line is used during sample collection with most commercially available samplers. Pressurized sampling requires an additional pump to provide positive pressure to the sample canister. A sample of air is drawn through a sampling train comprised of components that regulate the rate and duration of sampling into the pre-evacuated and passivated canister. After the air is collected the canister valve is closed, an identification tag is attached to the canister, and the canister is transported to the laboratory for analysis. Upon receipt at the laboratory the canister tag data is recorded and the canister is stored until analysis.

To analyze the sample a known volume of sample is directed from the canister through a solid multisorbent concentrator. A portion of the water vapour in the sample breaks through the concentrator during sampling to a degree depending on the multisorbent composition, duration of sampling, and other factors. Dry purging the concentrator with helium while retaining target compounds can further reduce water content of the sample. After the concentration and drying steps are completed, the VOCs are thermally desorbed, entrained in a carrier gas stream, and then focused in a small volume by trapping on a reduced temperature trap or a small volume multisorbent trap. The sample is then released by thermal desorption and carried onto a gas chromatographic column for separation.

The analytical strategy for US EPA Compendium Method TO-15A involves using a high-resolution gas chromatograph (GC) coupled to a mass spectrometer (MS). If the MS is a linear quadrupole system, it is operated either by continuously scanning a wide range of mass to charge ratios (SCAN mode) or by monitoring select ion monitoring mode (SIM) of compounds on the target list. If the MS is based on a standard ion trap design, only a scanning mode is used. Mass spectra for individual peaks in the total ion chromatogram are examined with respect to fragmentation pattern of ions corresponding to various VOCs including the intensity of primary and secondary ions. The fragmentation pattern is compared with stored spectra taken under similar conditions, in order to identify the compound.

For any given compound, the intensity of the primary fragment is compared with the system response to the primary fragment for known amounts of the compound. This establishes the compound concentration that exists in the sample. This method applies to ambient concentrations of VOCs of 0.5 parts per billion by volume (ppbv or 1 $\mu g/m^3$) and typically requires VOC enrichment by concentrating up to 1 L of a sample volume. The VOC concentration range for ambient air in many cases includes the concentration at which continuous exposure over a lifetime is estimated to constitute a 10^{-6} or higher lifetime risk of developing cancer in humans.

5.1.2 US EPA Method 0030

The US EPA has also developed a methodology suitable for sampling gaseous emissions from stationary sources for the determination of trace-level concentrations of propylene oxide. US EPA Method 0030 - Volatile Organic Sampling Train describes the methodology for the collection of volatile principle organic hazardous constituents (POHCs) (including propylene oxide) from the stack gas effluents of hazardous waste incinerators (US EPA, 1986). For the purpose of definition, volatile POHCs are those POHCs with boiling points less than 100°C. This method employs a 20 L sample of effluent gas containing volatile POHCs that is withdrawn from a gaseous effluent source at a flow rate of 1 liter per minute (L/min), using a glass-lined probe and a VOST.

The gas stream is cooled to 20°C by passage through a water-cooled condenser and volatile POHCs are collected on a pair of sorbent resin traps. Liquid condensate is collected in an impinger placed between the two resin traps. The first resin trap (front trap) contains approximately 1.6 grams (g) of Tenax and the second trap (back trap) contains approximately 1 g each of Tenax and a petroleum-based charcoal, 3:1 by volume. A total of six pairs of sorbent traps may be used to collect volatile POHCs from the effluent gas stream. Analysis of the traps is carried out by thermal desorption purge-and-trap by GC/MS. The VOST is designed to be operated at 1 L/min with traps being replaced every 20 minutes for a total sampling time of 2 hours. Traps may be analyzed separately or combined onto one trap to improve detection limit. The target detection limit of this method is 0.1 to 100 micrograms per cubic meter ($\mu g/m^3$) for selected POHCs collected on a set of sorbent traps using a total sample volume of 20 L or less.

5.1.3 NIOSH Method 1612

For occupational, personal and area monitoring, NIOSH recommends collecting propylene oxide on charcoal adsorption tubes with subsequent chemical analyses by GC (NIOSH Method 1612) (NIOSH, 1994). Sampling is conducted by drawing air through a solid sorbent (coconut shell

charcoal, 100 milligrams (mg) in the front section and 50 mg in the back section) tubes using a personal sampling pump calibrated to within ± 5% of the recommended flow rate with a sampling tube in line. The suggested flow rate is 0.01 to 0.2 L/min and the minimum volume collected should be 0.5 L and the maximum 5 L.

Air samples collected are shipped refrigerated to minimize migration of analyte from the front section to the back section of the absorbent. The contents of the tube are desorbed with carbon disulfide and the desorbate is analyzed by GC using a flame ionization detector (FID). The working range for concentrations of propylene oxide is 8 to 295 parts per million by volume (ppmv) (20 to 700 milligrams per cubic meter (mg/m^3)) for a 5 L air sample. The NIOSH has developed their methods based upon carbon adsorption because it is a universal adsorbent and a relatively inexpensive technique that requires simple, readily available laboratory equipment.

5.1.4 OSHA Method 88

The current methodology used by OSHA to determine propylene oxide in air is based on the coconut shell charcoal tube procedure developed by NIOSH but using a different sorbent tube (OSHA Method 88) (OSHA, 1991). Sampling is conducted by drawing air through standard size Anasorb-747 absorbent tubes using a personal sampling pump calibrated to within ± 5% of the recommended flow rate with a sampling tube in line. Each tube consists of two sections of Anasorb-747 separated by a urethane foam plug. The front section contains 140 mg and the back section contains 70 mg. These sections are held in place with glass wool plugs in a glass tube. The suggested flow rate is 0.1 L/min and the recommended volume collected is 5 L.

Air samples collected are shipped refrigerated to minimize migration of analyte from the front section to the back section of the absorbent. The Anasorb-747 is desorbed with carbon disulfide and the desorbate is analyzed by GC using a FID. The reliable detection limit of the overall procedure is 0.415 µg (micrograms) per sample (35 ppbv or 83 $\mu g/m^3$) for a 5 L air sample. This is the amount of propylene oxide spiked on an Anasorb-747 tube that, upon analysis, produces a peak similar in size to that of the detection limit of the analytical procedure. The reliable quantitation limit of propylene oxide determined through this technique is 0.415 µg per sample (35 ppbv or 83 $\mu g/m^3$) for a 5 L air sample. This is the smallest amount of propylene oxide that can be quantified within the requirements of 75% recovery and precision of ± 25% or better.

5.2 Alternative, Emerging Technologies

In general, most non-standard methods and technologies are variations or modifications of those referenced methods previously mentioned (Campbell and Moore, 1979; NIOSH, 1994; Mastrogiacomo et al., 1998). However, unique methods and technologies have been described (Brown and Wright, 1994; Levin and Lindahl, 1994). These unique methods and technologies include various passive/diffusive sampling approaches.

The most notable variations or modifications of referenced methods for the collection and analysis of volatile organic compounds (VOCs) (including propylene oxide) involve alternative types of sorbents to be used in conjunction with the accepted pump-and-tube sampling approaches. Of the alternative sorbents, porous polymers or silica gel are the most common. In addition, a new adsorbent high-surface-area graphitized carbon black (HSGCB) was found to be

an interesting alternative to the usual sorbents used for sampling VOCs such as propylene oxide (Mastrogiacomo et al., 1998).

A number of different analytical techniques have also been recommended. A method for detecting propylene oxide in air previously used by the NIOSH uses methanol Instead of other solvents for desorption and gas chromatography (GC) with a flame ionization detector (FID) for analysis (NIOSH, 1994). Campbell and Moore (1979) describe a method suitable for detecting propylene oxide in air that uses gas chromatography with a nitrogen/phosphorous detector (GC/NPD) for analysis and methanol to desorb the charcoal but with sonication to increase the desorption efficiency.

An increasing number of passive or diffusive samplers (gas badges or diffusion tubes) have been developed to determine concentrations of propylene oxide in air as an alternative to the pump-and-tube techniques. For diffusive sampling, the same collecting media (sorbent) as for pumped sampling can be used. The advantages of these samplers are that there are no moving parts to break down, regular flow calibration is unnecessary, and no bulky, expensive pumps are required. The badge or tube is exposed to ambient conditions for a set period of time (usually a longer period than for active pump sampling) and then analyzed by GC/FID or another similar analytical method (Brown and Wright, 1994; Levin and Lindahl, 1994). These devices are now considered to be as reliable as the more conventional pump-and-tube techniques.

Table 5-1 Method Advantages and Disadvantages

Method	Advantages	Disadvantages
U.S. EPA Compendium Method TO-15A	Addresses a large set of compounds Establishes method performance criteria for acceptance of data Provides quality control provisions Allows analysis for polar VOCs	Requires expensive analytical equipment Requires high level of operator skill
U.S. EPA Method 0030	NA	NA
NIOSH Method 1612	Uses a universal adsorbent Relatively inexpensive Requires simple, readily available laboratory equipment	NA
OSHA Method 88	NA	NA
Alternative sorbent types	NA	NA
Alternative analytical techniques	NA	NA
Passive samplers	No moving parts to break down Regular flow calibration unnecessary No bulky, expensive pumps required As reliable as more conventional techniques	NA

*NA denotes not available.

6.0 AMBIENT GUIDELINES

Current and/or recommended and proposed ambient guidelines from jurisdictions in Canada, United States and elsewhere (other than in Alberta) were reviewed for propylene oxide. These guidelines are presented in Table 6-1. In general, all jurisdictions have common uses for their guidelines in practice. These uses may include:

- reviewing permit applications for sources that emit air pollutants to the atmosphere,
- investigating accidental releases or community complaints about adverse air quality for the purpose of determining follow-up or enforcement activity,
- determining whether to implement temporary emission control actions under persistent adverse air quality conditions of a short-term nature.

The three principal approaches by which guidelines are developed for substances like propylene oxide include:

- Using an occupational exposure level (OEL) and dividing it by safety or adjustment factors. The most common OEL used by state agencies is the 8-hour threshold limit value (TLV) of 48,000 $\mu g/m^3$ (20 ppm) adopted by the American Conference of Governmental Industrial Hygienists (ACGIH). The safety or adjustment factors are intended to account for issues such as: differences between 8-hour exposures in the workplace and continuous 24-hour environmental exposures, increased susceptibility of some people in the general population versus the relatively healthy worker, and uncertainty in the margin of safety provided in an occupational exposure limit.
- Using non-carcinogenic risk assessment procedures. A no observed adverse effect level (NOAEL) – or lowest observed adverse effect level (LOAEL) if a NOAEL is unavailable – from a suitable animal or human study is used. It is then divided by a series of adjustment factors. The adjustment factors are intended to account for issues such as: differences between animals and humans, sensitivity of high risk individuals, use of a LOAEL instead of a NOAEL, and for extrapolation from less-than-lifetime exposures to chronic exposure.
- Using carcinogenic risk assessment procedures. Pre-existing cancer risk assessment information summarized by others (e.g. US EPA Integrated Risk Information System summary data) are used to establish ambient air levels based on acceptable levels of increased lifetime cancer risk, such as 1 in 100,000 (10^{-5}).

For the most part, the guidelines in Table 6-1 are derived based on extra thoracic respiratory effects in rats exposed through inhalation (non-carcinogenic effect endpoint) or formation of tumours in the nasal cavity of both rats and mice (carcinogenic effect endpoint). Almost all of the guidelines listed in Table 6-1 are for chronic exposure durations. Further information on how these guidelines were developed and how they are used in practice is provided in Appendix A.

6.1 Canada

Ontario MOE (2001) adopted a risk specific concentration (RsC) of 0.3 $\mu g/m^3$ (0.13 ppb) as the annual AAQC based on the US EPA inhalation unit risk of 3.7E-06 per ($\mu g/m^3$), and using a 70-

kg body weight adult breathing 20 m^3/day and a 1 in 1,000,000 risk level. A 24-hour AAQC of 1.5 $\mu g/m^3$ (0.6 ppb) was adopted, which was a factor of five times the annual AAQC. A 30-minute averaging time interim POI of 450 $\mu g/m^3$ (189 ppb) was chosen pending the outcome of consultation on a risk management framework by Ontario MOE.

AAQC represent human health or environmental effect-based values, and are normally set at a level not expected to cause adverse effects based on continuous exposure. As such, economic factors, such as technical feasibility and costs, are not explicitly considered when establishing AAQCs. On the other hand, emission sources in Ontario are required to comply with the Point of Impingement (POI) standards, and the development of POI standards does take into account economic and other factors.

6.2 United States

No health-based criteria existed for propylene oxide from the US Agency for Toxic Substances and Disease Registry.

The US EPA developed a chronic inhalation reference concentration (RfC) of 30 $\mu g/m^3$ (13 ppb) (US EPA, 2001). The RfC is based on a two-year inhalation exposure study to rats and a LOAEL of 71 mg/m^3 (30 ppm) for on extra thoracic respiratory effects in rats. The US EPA used data from a two-year rat and mice inhalation study to derive an inhalation unit risk of 3.7E-06 per ($\mu g/m^3$). The RfC and inhalation unit risk are intended for use by US EPA staff in risk assessments, decision-making and regulatory activities.

Five of the US agencies reviewed – those in California, Louisiana, Michigan, New Jersey, and Ohio – have adopted or derived their values from the US EPA RfC (30 $\mu g/m^3$ or 13 ppb) and/or the inhalation unit risk (3.7E-06 per $\mu g/m^3$).

Only two state agencies listed in Table 6-1 – those in New Hampshire and Oklahoma – use the ACGIH 8-hour TLV (48,000 $\mu g/m^3$ or 20 ppm) in development of various ambient guidelines for propylene oxide (refer to Appendix A). Although guidelines were reported for propylene oxide for agencies in Vermont and Wisconsin, no information was available to explain their derivation.

6.3 European Union

No information about propylene oxide guidelines in European member countries was found.

6.4 Australia/ New Zealand

The New Zealand Ministry of Environment and Ministry of Health recently proposed guidelines for selected air toxics; however, propylene oxide was not included (New Zealand, 2000).

Table 6-1 Summary of Air Quality Guidelines for Propylene Oxide (refer to Appendix A for agency reference)

Agency	Guideline Title	Guideline Value [µg/m³] Averaging Time:			
		30-min	1-hour	24-hour	Annual
Ontario MOE	Ambient air quality criterion (AAQC):			1.5	0.3
	Maximum point of impingement (POI):	450			
US ATSDR	Guideline does not exist.				
US EPA	Reference Concentration (RfC):				30
	Risk specific concentration (RsC):[1]				3
California EPA	Acute reference exposure level (REL):		3,100		
	Chronic reference exposure level (REL):				30
	Risk specific concentration (RsC):[1]				3
Louisiana DEQ	Ambient air standard (AAS):				27
Michigan DEQ	Initial threshold screening level (ITSL):			30	
	Initial risk screening level (IRSL):				0.3
	Secondary risk screening level (SRSL):				3
New Hampshire DES	24-hour ambient air limit (AAL):			171	
	Annual AAL:				30
New Jersey DEP	Risk assessment approach is used:				
	Hazard quotient (HQ):				30
	Risk specific concentration (RsC):[1]				3
North Carolina ENR	Guideline does not exist.				
Ohio EPA	Risk specific concentration (RsC):[1]				3
Oklahoma DEQ	Maximum acceptable ambient concentration (MAAC):			480	
Rhode Island DEM	Guideline does not exist.				
Texas Natural Resource Conservation Commission (TRNCC)	Effects screening level (ESL):		210		21
Vermont ANR	Hazardous ambient air standard (HAAS):				0.01
Washington State DOE	Acceptable source impact level (ASIL):				0.27
Wisconsin DNR	Ambient air concentration (AAC):[2]			1,140	

[1] The RsC is not used for any specific purposes by the respective agency. It is shown here to illustrate an exposure concentration in air associated with an inhalation unit risk factor used by the agency and a 1 in 100,000 lifetime cancer risk (risk criteria used in Alberta).

[2] Proposed.

NOTE: 1 $\mu g/m^3$ = 0.42 ppb at 25°C and 1 atmosphere

7.0 DISCUSSION

When establishing an ambient air guideline in the form of a concentration limit with a corresponding duration (i.e. averaging time), a number of factors may be taken into account for an air pollutant:

- nature of adverse health effects and conditions of exposure (e.g. exposure concentrations and duration) associated with these effects,
- estimated or actual degree of exposure of receptors, and in particular receptor groups that may be sensitive to the air pollutant,
- available technologies and associated economics for routinely or periodically monitoring for the pollutant in air,
- availability and suitability of approaches for screening and estimating ambient ground-level concentrations in order to compare to the guidelines for permit applications or other situations.

Ambient air guidelines in the form of a short-term (acute) and long-term (chronic) duration are discussed below for propylene oxide. Ideally the guidelines would serve to address exposures related to humans, animals and vegetation. No direct exposure-related information was obtained for vegetation, therefore the discussion emphasizes human and animal (as surrogates for human) exposures.

7.1 Acute Exposure Conditions

There are no facilities reported in Alberta emitting propylene oxide above thresholds set for the National Pollutant Release Inventory (NPRI, 1999). As indicated previously, it is possible that propylene oxide is emitted in Alberta in such small amounts that the facilities are not required to report to the NPRI.

The literature reports that acute (short-term) exposure of animals to propylene oxide causes a number of adverse responses. These include tearing of the eyes, salivation, respiratory irritation (lung, nasal passages), vomiting, central nervous system depression, and death. These types of responses have been observed in controlled animal studies at concentrations ranging from 48 to 38,000 mg/m^3 (20 to 16,000 ppm) over exposure durations ranging from 30 min. to 7 hrs. These types of responses have been reported from occupational studies; however, evidence of the direct-acting effect of propylene oxide is lacking because mixed chemical exposures occurred for the occupational situations reported. With respect to non-occupational circumstances, acute exposure conditions are unlikely for the general population because of the absence of major sources.

The majority of agencies reviewed do not have an air quality guideline for propylene oxide for acute exposure conditions. Cal EPA adopted a 1-hour guideline of 3,100 µg/m^3 (1,300 ppb) based on nasal irritation in exposed mice. Texas adopted a 1-hour guideline of 210 µg/m^3 (88 ppb); however, the origin of this guideline is unknown.

Two agencies adopted 24-hour guidelines from occupational exposure limits (New Hampshire DES and Oklahoma DEQ). Wisconsin adopted a 24-hour guideline of 1,140 $\mu g/m^3$ (480 ppb), however the origin of this guideline is unknown.

The use of OELs for the development of ambient guidelines is cautioned. There are limitations in the direct and indirect application of OELs for ambient air quality guidelines for a number of reasons:

- OELs are based on the information gathered in workplace, through experience from medical research and practice, from experimental human and animal studies, and from a combination of these sources. Often they are based upon averaged tolerated doses from actual repeated industrial exposures. In this respect, they would be considered very accurate at predicting human adverse health effects in industrial exposure situations.
- OELs are determined for a population of workers who are essentially healthy and who fall within a working age group of about 17 to 65 years. These individuals are supposedly in the prime of life, and potentially less susceptible to the effects of hazardous substances than other members of the public. Individuals vary in sensitivity or susceptibility to hazardous substances, with the elderly and infants in general being more susceptible than healthy workers.
- For most substances, a worker during a normal work schedule (8 hours per day, 5 days per week) receives 40 hours of exposure per week with daily breaks and extended weekend periods in which the body may rid itself of the accumulated substances before elevated levels are reached. For a person living continuously in an environment containing such substances; however, these recovery periods do not exist.

For these reasons, agencies using OELs have a policy of adjusting them downward with the use of safety or adjustment factors to derive guidelines for environmental (ambient) settings. The OELs are considered surrogates for benchmark values for ambient exposures only because they tend to be based upon a large body of toxicological, epidemiological, and/or clinical evidence pertaining to human exposure (albeit in the workplace). Uncertainty exists in terms of whether too much (or too little) safety is inherent in ambient air guidelines developed from OELs.

7.2 Chronic Exposure Conditions

Propylene oxide has been shown to be a direct acting carcinogen, producing tumours at the site of exposure (in the nasal cavity) in rats and mice intermittently exposed propylene oxide at concentrations greater than 950 mg/m^3 (400 ppm) for 103 weeks. The review of human health effects information from propylene oxide exposures indicated that there is no conclusive evidence that it is a carcinogen on the basis of epidemiological studies in the workplace. It is important to note that exposure to other chemicals also occurred in many of these studies. In addition, difficulties are normally encountered in establishing exposure-response information due to differences in lifestyle, individual metabolism, and the healthy worker effect in such studies. As exposure to propylene oxide has been shown to cause cancer in experimental animals, it is treated as a potential carcinogen by most agencies regulating its use in the environment.

Non-cancer responses reported to occur during chronic-exposure animals studies associated with inhalation of propylene oxide include decreased growth rate, nasal epithelium inflammation, irritation of respiratory passages, lung and nerve damage, ovarian and testicular degeneration, skeletal muscle degeneration, mild developmental effects, and death. These types of responses have been observed at exposure concentrations ranging from 70 to 3,400 mg/m^3 (30 to 1,440 ppm).

All of the agencies whose air quality guidelines were reviewed, except for Rhode Island DEM, have adopted chronic (long-term) guidelines for propylene oxide based on carcinogenic and/or non-carcinogenic endpoints. Five agencies use a carcinogenic endpoint to derive their respective guideline – using the US Environmental Protection Agency's inhalation unit risk of 3.7E-06 per $\mu g/m^3$. In addition four agencies have a chronic guideline – using the US Environmental Protection Agency's reference concentration of 30 $\mu g/m^3$ (13 ppb). Texas adopted a chronic guideline of 21 $\mu g/m^3$ (9 ppb); however, the origin of this guideline is unknown.

8.0 REFERENCES

Agurell, E., H. Cerderberg, K. Ehrenberg, K. Lindahl-Kiessling, U, Rannug and M. Törnqvist 1991. Genotoxic Effects of Ethylene Oxide and Propylene Oxide: A Comparative Study. *Mutat. Res.* 250: 229-237. Cited In: Farooqi et al. (1993).

Alberta Environment (AENV). 2000. Alberta Ambient Air Quality Guidelines. Environmental Sciences Division, Alberta Environment. Edmonton, AB. February 2000. 3 pp.

Aranyi, C. W.J. O'Shea, J.A. Graham and F.J. Miller. 1986. The Effects of Inhalation of Organic Chemical Air Contaminants on Murine Lung Host Defences. *Fundam. Appl. Toxicol.* 6: 713-720. Cited In: IARC (1994).

Arms, A.D. and C.C. Travis. 1988. *Reference Physiological Parameters in Pharmacolkinetic Modelling* (Technical Report No. EPA/600/6-88/004), Washington DC, US Environmental Protection Agency. Cited In: IARC (1994).

Benson, L.O. and M.J. Teta. 1993. Mortality due to Pancreatic and Lymphopoietic Cancers in Chlorohydrin Production Workers. *Br. J. Ind. Med.* 50: 710-716. Cited In: Olsen et al. (1997).

Boogaart, P.J., P.S. Rocchi and N.J. van Sittert. 1999. Biomonitoring of Exposures to Ethylene Oxide and Propylene Oxide by Determination of Hemoglobin Adducts: Correlation Between Airborne Exposure and Adduct Levels. *Int. Arch. Occup. Environ. Health.* 72: 142-150.

Bootman, J., D.C. Lodge and H.E. Whalley. 1979. Mutagenic Activity of Propylene Oxide in Bacterial and Mammalian Systems. *Mutat. Res.* 67: 101-112. Cited In: IPCS (1985).

Brown, R.H. and M.D. Wright. 1994. Diffusive Sampling Using Tube-type Samplers. *Analyst.* 119: 75-79.

California Air Pollution Control Officers Association (CAPCOA). 1993. Air Toxics Hot Spots Program Revised 1992 Risk Assessment Guidelines. CAPCOA Toxics Committee, Cameron Park, CA. October 1993.

California Environmental Protection Agency (Cal EPA). 1999a. Determination of Acute Reference Exposure Levels for Airborne Toxicants. Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section, California Environmental Protection Agency. Oakland, CA. March 1999.

Cal EPA. 1999b. Air Toxics Hot Spots Program Risk Assessment Guidelines Part II. Technical Support Document for Describing Available Cancer Potency Factors. Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section, California EPA. Oakland, CA. April 1999.

Campbell, D.N. and R.H. Moore. 1979. The Quantitative Determination of Acrylonitrile, Acrolein, Acetonitirle and Acetone in Workplace Air. *Amer. Indust. Hyg. Assoc. Journal*. 40: 904-909.

Couch, R., L. Ehrenberg, A.-L. Magnusson, R. Nilsson, M.E. de la Rosa and M. Törnqvist. 1996. *In Vivo* Dosimetry of Ethylene Oxide and Propylene Oxide in Cynomolgus Monkey. *Mutat. Res.* 357: 17-23.

Dean, B.J. and G. Hodson-Walker. 1979. An *In Vitro* Chromosome Assay Using Cultured Rat Liver Cells. *Mutat. Res.* 64: 329-337. Cited In: IPCS (1985).

Environment Canada (EC). 1985. *Propylene Oxide: Environmental and Technical Information for Problem Spills*, Technical Services Branch, Environmental Protection Programs Directorate, Environmental Protection Service, 88 pp.

Ehrenberg, L. and S. Hussain. 1981. Genetic Toxicity of Some Important Epoxides. *Mutat. Res.* 86: 1-113. Cited In: Farooqi et al. (1993).

Eldridge, S.R., M.S. Bogdanffy, M.P. Jokinen and L.S. Andrews. 1995. Effects of Propylene Oxide on Nasal Epithelium Cell Proliferation in F344 Rats. *Fundam. Appl. Toxicol.* 27: 25-32.

Farooqi, Z., M. Törnqvist, L. Ehrenberg and A.T., Natarajan. 1993. Genotoxic Effects of Ethylene Oxide and Propylene Oxide in Mouse Bone Marrow Cells. *Mutat. Res.* 288: 223-228.

Genium Publishing Corporation (Genium). 1999. *Genium's Handbook of Safety, Health and Environmental Data for Common Hazardous Substances*, McGraw Hill, New York, NY.

Golka, K., H. Peter, B. Denk and J.G. Filser. 1989. Pharmacokinetics of Propylene and its Reactive Oxide Propylene Oxide in Sprague-Dawley Rats. *Arch. Toxicol. Suppl.* 13: 240-242. Cited In: IARC (1994).

Greenberg, H.I., M.G. Ott and R.E. Shore. 1990. Men Assigned to Ethylene Oxide Production or Other Ethylene Oxide Related Chemical Manufacturing: A Mortality Study. *Br. J. Ind. Med.* 47: 21-30. Cited In: Olsen et al. (1997).

Hackett, P.L., M.G. Brown, R.L. Buschbom, M.L. Clark, R.A. Miller, R.L. Music, S.E. Rowe, R.E. Schirmer and M.R. Sikov. 1982. *Teratogenic Study of Ethylene Oxide and Propylene Oxide and N-Butyl Acetate*, Richland, Washington, Batelle Pacific Northwest Laboratories (Prepared for NIOSH) (PB 83-258038).

Hardin, B.D., R.L. Schuler, P.M. McGinnis, R.W. Niemeier and R.J. Smith. 1983a. Evaluation of Propylene Oxide for Mutagenic Activity in 3 *In Vivo* test systems. *Mutat. Res.* 117: 337-344. Cited In: IPCS (1985).

Hardin, B.D., R.W. Niemeier, M.R. Sikov and P.L. Hackett. 1983b. Reproductive-Toxicological Assessment of Epoxides Ethylene Oxide, Propylene Oxide, Butylene Oxide, and Styrene Oxide. *Scand. J. Work Environ. Health.* 9: 91-102.

Harris, S.B., J.L Schardien, C.E. Ulrich and S.A. Ridlon. 1989. Inhalation Developmental Toxicity Study of Propylene Oxide in Fisher 344 Rats. *Fundam. Appl. Toxicology.* 13: 323-332.

Haseman, J.K. and J.R. Hailey. 1997. An Update of the National Toxicology Program Database on Nasal Carcinogens. *Mutat. Res.* 380: 3-11.

Hayes, W.C., H.D. Kirk, T.S. Gushow and J.T. Young. 1988. Effect of Inhaled Propylene Oxide on Reproductive Parameters in Fisher 344 Rats. *Fundam. Appl. Toxicol.* 10: 82-88.

Högstedt, C., E. Bergmark, M. Törqvist and S. Osterman-Golkar. 1990. Chromosomal Aberrations and Micronuclei in Lymphocytes in Relation to Alkylation of Hemoglobin in Workers Exposed to Ethylene Oxide and Propylene Oxide. *Hereditas.* 113: 133-138.

Högstedt, C., N. Malmqvist and B. Wadman. 1979a. *Ethylene Oxide and Leukemia – Case Reports*. Reg Hospital, 2-70185, Örebva, Sweden. Cited In: Thiess et al. (1981b).

Högstedt, C., N. Malmqvist and B. Wadman. 1979b. Leukemia in Workers Exposed to Ethylene Oxide. *J. Am. Med. Assoc.* 241: 1132-1133. Cited In: Thiess et al. (1981b).

Högstedt, C., O. Rohlén, B.S. Berndtsson, O. Axelson and L. Ehrenberg. 1979c. A Cohort Study of Mortality and Cancer Incidence in Ethylene Oxide Production Workers. *Br. J. Ind. Med.* 36: 276-280. Cited In: Thiess et al. (1981b).

Hussain, S. 1981. *Mutagenic Action of Radiation and Chemicals: Parameters Affecting the Response of Test Systems* [Dissertation]. –Stockholm, Sweden: University of Stockholm. Cited In: Högstedt et al. (1990).

International Agency for Research on Cancer (IARC). 1994. Propylene Oxide. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Some Industrial Chemicals, Vol 60.* IPCS and IARC, Lyon. pp 181-213.

International Programme on Chemical Safety (IPCS). 1988. *Propylene Oxide Health and Safety Guide No. 15.* United Nations Environmental Programme, International Labour Organisation, World Health Organization, Geneva, Switzerland (available on-line at http://www.inchem.org/documents/hsg/hsg/hsg015.htm).

IPCS. 1985. *Environmental Health Criteria 56, Propylene Oxide*, United Nations Environmental Programme, International Labour Organisation, World Health Organization, Geneva, Switzerland (available on-line at http://www.inchem.org/documents/ehc/ehc/ehc56.htm).

Jacobson, K.H., E.B. Hackley and L. Feinsilver. 1956. The Toxicity of Inhaled Ethylene Oxide and Propylene Oxide Vapours. *Arch. Ind. Health.* 13: 237-244. Cited In: IPCS (1985).

Jensen, O. 1981. Contact Allergy to Propylene Oxide and Isopropyl Alcohol in Skin Disinfectant Swab. *Contact. Derm.* 7: 148-150. Cited In: IARC (1994); IPCS (1985).

Kahlich, D., U. Wiechern, J. Lidner. 2001. *Ullman's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH, Weinheim, Germany, http://jws-edck.interscience.wiley.com:8087.

Kautiainen, A and M. Törnqvist. 1991. Monitoring Exposure to Simple Epoxides and Alkenes Through Gas Chromatographic Determination of Hemoglobin Adducts. *Int. Arch. Occup. Environ. Health.* 63: 27-31. Cited In: IARC (1994).

Ketel, W.G. Van. 1979. Contact Dermatitis from Propylene Oxide. *Contact Dermatit.* 5: 191-192. Cited In: IARC (1994); IPCS (1985).

Kuper, C.F., P.G. Reuzel, and V.J. Feron. 1988. Chronic Inhalation Toxicity and Carcinogenicity Study of Propylene Oxide in Wistar Rats. *Fd. Chem. Toxic.* 26(2): 159-167.

Levin, J.O. and R. Lindahl. 1994. Diffusive Air Sampling of Reactive Compounds – A Review. *Analyst.* 119: 79-83.

Lewis, R.J. 1993. *Hawley's Condensed Chemical Dictionary, Twelfth Edition.* Van Nostrand Reinhold Company, New York, NY.

Lewis, R.J. 2000. *Sax's Dangerous Properties of Industrial Materials, Tenth Edition.* Wiley Interscience, John Wiley & Sons, New York, NY.

Lide, D.R. 2001. *CRC Handbook of Chemistry and Physics, 82nd Edition*, CRC Press, Boca Raton, Florida,FL.

Louisiana Administrative Code (LAC). Title 33 Environmental Quality, Part III Air, Chapter 51. Louisiana Department of Environmental Quality. Baton Rouge, LA.

Lynch, D.W., T.R. Lewis, W.J. Moorman, J.B. Lal, J.R Burg, D.K. Guilati, P.M. Zavos and P.S. Sabharwal. 1984c. Toxic and Mutagenic Effects of Inhalaled Ethylene Oxide and Propylene Oxide on Spermatogenic Functions in Monkeys. *Toxicologist.* 3: 60. Cited In: IPCS (1985).

Lynch, D.W., T.R. Lewis, W.J. Moorman, J.R. Burg, D.H. Groth, A. Khan, L.J. Ackerman and B.Y. Cockerell. 1984a. Carcinogenic and Toxicological Effects of Inhaled Ethylene Oxide and Propylene Oxide in F344 Rats. *Toxicol. Appl. Pharmacol.* 76: 69-84.

Lynch, D.W., T.R. Lewis, W.J. Moorman, J.R. Burg, D.K. Gulati, P. Kaur and P.S. Sabharwal. 1984b. Sister-Chromatid Exchanges and Chromosome Aberrations in Lymphocytes from Monkeys Exposed to Ethylene Oxide and Propylene Oxide by Inhalation. *Toxicol. Appl. Pharmacol.* 76(1): 85-95. Cited In: IPCS (1985).

Mastrogiacomo, A.R., E. Pierni, L. Sampaolo, and F. Bruner. 1998. Evaluation of a New Carbon Black Employed in Sampling Volatile Organic Compounds. *Journal of Chromatography A*. 810: 131-139.

McLaughlin, R.S. 1946. Chemical Burns of the Human Cornea. *Am. J. Ophthalmol.* 29: 1355-1362. Cited In: IPCS (1985).

Michigan Administrative Code (MAC). Air Pollution Control Rules. Part 2 Air Use Approval, R 336.1201 - 336.1299. Air Quality Division, Department of Environmental Quality. Lansing, MI.

National Institute for Occupational Safety and Health (NIOSH). 1994. NIOSH Manual of Sampling and Analytical Methods – 4th Edition, Volume 3, Method 1612. US Department of Health, Education, and Welfare, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Physical Sciences and Engineering, Cincinnati, OH, 1994.

National Pollutant Release Inventory (NPRI). 1998, 1997, 1996 and 1995. National Pollutant Release Inventory, http://www.ec.gc.ca/pdb/npri/npri_preinfo_e.cfm.

NPRI. 1999. *National Pollutant Release Inventory*. http://www.ec.gc.ca/pdb/npri/npri_dat_rep_e.cfm.

New Hampshire Administrative Rule. Chapter Env-A 1400. Regulated Toxic Air Pollutants. New Hampshire Department of Environmental Services. Concord, NH.

New Jersey Administrative Code (NJ AC). Title 7, Chapter 27, Subchapter 8. Permits and Certificates for Minor Facilities (and Major Facilities without an Operating Permit). New Jersey Department of Environmental Protection. Trenton, NJ.

New Jersey Department of Environmental Protection (NJ DEP). 1994. Technical Manual 1003. Guidance on Preparing a Risk Assessment for Air Contaminant Emissions. Air Quality Permitting Program, Bureau of Air Quality Evaluation, New Jersey Department of Environmental Protection. Trenton, NJ. Revised December 1994.

New Zealand Ministry for the Environment and Ministry of Health (New Zealand). 2000. Proposals for Revised and New Ambient Air Quality Guidelines. Discussion Document. Air Quality Technical Report No 16. Prepared by the Ministry for the Environment and the Ministry of Health. December 2000. 86 pp.

Nilsson, R., B. Molholt and E. Sargent. 1991. Quantitative Assessment of a Human Carcinogenic Potency for Propylene Oxide. *Reg. Toxicol. Pharmacol.* 14: 229-224.

North Carolina Administrative Code (NCAC). North Carolina Air Quality Rules 15A NCAC 2Q.0700 – Air Quality Permit Procedures (Toxic Air Pollutant Procedures). North Carolina Department of Environment and Natural Resources. Raleigh, NC.

NCAC. North Carolina Air Quality Rules 15A NCAC 2D.1100 – Air Pollution Control Requirements (Control of Toxic Air Pollutants). North Carolina Department of Environment and Natural Resources. Raleigh, NC.

Occupational Safety and Health Administration (OSHA). 1991. OSHA Sampling and Analytical Methods, Propylene Oxide Method 88. Organic Methods Evaluation Branch, Occupational Safety and Health Administration, US Department of Labor, OSHA Salt Lake Technical Center, Salt Lake City, UT, June 1991.

Ohio Environmental Protection Agency (Ohio EPA). 1994. Review of New Sources of Air Toxic Emissions. Proposed for Public Comment. Division of Air Pollution Control, Ohio EPA. Columbus, OH. January 1994. 31 pp.

Ohnishi, A. and Y. Murai. 1993. Polyneuropathy due to Ethylene Oxide, Propylene Oxide and Butylene Oxide. *Environ. Res.* 60: 242-247.

Ohnishi, A., T. Yamamoto, Y. Murai, Y. Hayashida, H. Hori and I. Tanaka. 1988. Propylene Oxide Causes Central-Peripheral Distal Axonopathy in Rats. *Arch. Environ. Health.* 43: 353-356. Cited In: IARC (1994).

Oklahoma Administrative Code (OAC). Title 252. Chapter 100. Air Pollution Control. 100:252-41 - Control of Emission of Hazardous and Toxic Air Contaminants. Oklahoma Department of Environmental Quality. Oklahoma City, OK.

Olsen, G.W., S.L. Lacy, K.M. Bodner, M. Chau, T.G. Arceneaux, J.B. Cartmill, J.M. Ramlow and J.M. Boswell. 1997. Mortality from Pancreatic and Lymphopoietic Cancer Among Workers in Ethylene and Propylene Chlorohydrin Production. *Occup. Environ. Med.* 54: 592-598.

Ontario Ministry of the Environment (Ontario MOE). 2001. Ontario Air Standards for Propylene Oxide. Standards Development Branch, Ontario Ministry of the Environment. Toronto, ON. March 2001. 58 pp.

Pero, R.W., S. Osterman-Golkar and B. Högstedt. 1985. Unscheduled DNA Synthesis Correlated to Alkylation of Hemaglobin in Individuals Occupationally Exposed to Propylene Oxide. *Cell Biol. Toxicol.* 1: 309-314. Cited In: IARC (1994).

Pero, R.W., T. Bryngelsson, B. Widegren, B. Högstedt and H. Welinder. 1982. A Reduced Capacity for Unscheduled DNA Synthesis in Lymphocites from Individuals Exposed to Propylene Oxide and Ethylene Oxide. *Mutat. Res.* 104: 193-200.

Renne, R.A., W.E. Giddens, G.A. Boorman, R. Kovatch, J.E. Haseman and W.J. Clark. 1986 Nasal Cavity Neoplasia in F344/N Rats and (C57BL/6 X C3H)F_1 Mice Inhaling Propylene Oxide for up to Two Years. *JNCI* 77(2): 573-581.

Reuzel, P.G. and C.F. Kuper. 1984. *Chronic (28-Month) Inhalation Toxicity/Carcinogenicity Study of 1,2-Propylene Oxide in Rats*, Ziest, The Netherlands, TNO, Division of Nutrition and Food Research (Addendum to Report No. V82.215/280853. Cited In: IPCS (1985).

Rhode Island Department of Environmental Management (DEM). 1992. Air Pollution Control Regulation No. 22. Division of Air and Hazardous Materials, Rhode Island Department of Environmental Management. Providence, RI.

Ríos-Bianco, M.N., K. Plna, T. Faller, W. Kessler, K. Håkansson, P.E. Kreuzer, A. Ranasinghe, J.G. Filser, D. Segerbäck and J.A. Swenberg. 1997. Propylene Oxide: Mutagenisis, Carcinogenisis and Molecular Dose. *Mutat. Res.* 380: 179-197.

Ríos-Bianco, M.N., T.H. Faller, J.Nakamura, W. Kessler, P.E. Kreuzer, A. Ranasinghe, J.G. Filser and J.A. Swenberg. 2000. Quantitation of DNA and Hemoglobin Adducts and Apurinic/Apyrimindinic Sites in Tissues of F344 Rats Exposed to Propylene Oxide by Inhalation. *Carcinogenesis.* 21(11): 2011-2018.

Rowe, V.K., R.L. Hollingsworth, F. Oyen, D.D. McCollister and H.C. Spencer. 1956. Toxicity of Propylene Oxide Determined on Experimental Animals. *Arch. Ind. Health.* 13: 228-236. Cited In: IPCS (1985).

Segerbäck, D. 1983. Alkylation of DNA and Haemoglobin in the Mouse Following Exposure to Ethene and Ethene Oxide. *Chem.–Biol. Interact.* 45: 139-151. Cited In: Farooqi et al. (1993).

Segerbäck, D., S. Osterman-Golkar, B. Molholt and R. Nilsson. 1994. *In Vivo* Tissue Dosimetry as a Basis for Cross-Species Extrapolation in Cancer Risk Assessment of Propylene Oxide. *Reg. Toxicol. Pharmacol.* 20: 1-14.

Setzer, J.V., W.S. Brightwell, J.M. Russo, B.L. Johnson, D.L. Lynch, G. Madden, J.R. Burg and H. Sprinz. 1996. Neurophysiological and Neuropathological Evaluation of Primates Exposed to Ethylene Oxide and Propylene Oxide. *Toxicol. Indust. Health.* 12(5): 667-682.

Sina, J.F., C.L. Bean, G.R. Dysart, V.I. Taylor and M.O. Bradley. 1983. Evaluation of the Alkaline Elution/Rat Hepatocycte Assay as a predictor of Carcinogenic/Mutagenic Potential. *Mutat. Res.* 113: 357-391. Cited In: IPCS (1985) and IARC (1994).

Sprinz, H., H. Matzke and J. Carter. 1982. *Neuropathological Evaluation of Monkeys Exposed to Ethylene Oxide and Propylene Oxide*, Kansas City, Missouri, Midwest Research Institute (Prepared for NIOSH) (PB 83-134817). Cited In: IPCS (1985).

Svensson, K., K. Olofsson and S. Osterman-Golkar. 1991. Alkylation of DNA and Hemoglobin in the Mouse Following Exposure to Propene and Propylene Oxide. *Chem.-Biol. Interact*. 78: 55-66. Cited In: Farooqi et al. 1993).

Texas Natural Resource Conservation Commission (TNRCC). 2001. Toxicology & Risk Assessment (TARA) Section Effects Screening Levels. http://www.tnrcc.state.tx.us/permitting/tox/index.html (accessed 6 September 2001).

Thiess, A.M., H. Schwegler, I. Fleig and W.G. Stocker. 1981a. Mutagenicity Study of Workers Exposed to Alkylene Oxides (Ethylene Oxide/Propylene Oxide) and Derivatives. *J. Occup. Med*. 23: 343-347.

Thiess, A.M., R. Frenzel-Beyme, R. Link and W.H. Stocker. 1981b. Mortality Study on Employees Exposed to Alkylene Oxides (Ethylene Oxide/Propylene Oxide) and Derivatives. In: *Proceedings of the International Symposium on Prevention of Occupational Cancer, Helsinki, Finland*. pp. 249-259.

Törnquist, M. and L. Ehrenberg. 1990. Approaches to Risk Assessment of Automotive Engine Exhausts. In: Vainio, H., M. Sorsa, A.J. McMicheal (eds.). *Complex Mixtures and Cancer Risk* (IARC Scientific Publications No. 104), Lyon, IARC, pp277-287. Cited In: IARC (1994).

United States Environmental Protection Agency (US EPA). 2001. Integrated Risk Information System. http://www.epa.gov/iris/ (accessed 8 August 2001).

US EPA. 1999. Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air – 2nd Edition. US Environmental Protection Agency, Office Research and Development, National Risk Management Research Laboratory, Center for Environmental Research Information. Cincinnati, Ohio. January 1999. EPA/625/R-96/010b.

US EPA. 1994. *US EPA IRIS Substance File – Propylene Oxide*. http://www.epa.gov/iris/subst/0403.htm.

US EPA. 1986. Volatile Organic Sampling Train (VOST) Method 0030, SW-846 Manual (Test Methods for Evaluating Solid Waste, Physical/Chemical Methods), Chapter 10, Volume II, 3rd Edition, 1986. Superintendent of Documents, US Government Printing Office, Washington, DC. Document Number 955-001-00000-1.

United States National Toxicology Program (US NTP). 1985. *Toxicology and Carcinogenesis Studies of Propylene Oxide in F344/N Rats and B6C3F1 Mice (Inhalation Studies)*, Research Triangle Park, North Carolina, National Toxicology Program (NTP Technical Report Series No. 267) (PB 851779653).

US NTP. 1984. *Toxicology and Carcinogenesis Studies of Propylene Oxide in F344/N Rats and B6C3F1 Mice (Inhalation Studies)*, Research Triangle Park, North Carolina, National Toxicology Program (NTP 83-020) (NIH Publication No. 84-2523). Cited In: IPCS (1985).

US NTP. 1983. *Draft technical Report on the Toxicity and Carcinogenicity of Propylene Oxide (CAS No. 75-56-9) in F344/N Rats and B6C3F1 Mice (Inhalation Study)*, Research Triangle Park, North Carolina, National Toxicology Program (NIH Publication No. 84-2523). Cited In: Lynch et al. (1984a).

Van Sittert, N.Y. and E.W. van Vliet. 1994. Monitoring Occupational Exposure to Some Industrial Chemicals by the Determination of Hemoglobin Adducts. *Clin. Chem.* 40(7) (in press). Cited In: IARC (1994).

Vermont Agency of Natural Resources (Vermont ANR). 2001. Vermont Air Pollution Control Regulations. State of Vermont Agency of Natural Resources. Air Pollution Control Division. Waterbury, VT. 29 November 2001. 187 pp.

Verschueren, K. 2001. *Handbook of Environmental Data on Organic Chemicals, Fourth Edition*, Wiley Interscience, John Wiley & Sons, New York, NY.

Vogel, E.W. and M.J. Nivard. 1998. Genotoxic Effects of Inhaled Ethylene Oxide, Propylene Oxide and Butylene Oxide on Germ Cells: Sensitivity of Genetic Endpoints in Relation to Dose and Repair Status. *Mutat. Res.* 405: 259-271.

Washington Administrative Code (WAC). Chapter 173-460 WAC. Controls For New Sources Of Toxic Air Pollutants. Washington State Department of Ecology. Olympia, WA.

Weisburger J.H. and G.M. Williams. 1975. *Chemical Carcinogens, Chapt 6.* In: Doull J., C.D. Klassen, M.O. Amdur (eds.) *Casarett and Doull's Toxicology*. 2d ed. Macmillan, New York, NY, pp 84-138. Cited In: Renne et al. (1986).

Wisconsin Administrative Code (WAC). Air Pollution Control Rules. Chapter NR 445. Control of Hazardous Pollutants. Wisconsin Department of Natural Resources. Madison WI.

APPENDIX A

Review of Air Quality Guidelines for Propylene Oxide Used by Agencies in North America and Elsewhere

Agency:

Ontario Ministry of the Environment (OME).

Propylene Oxide Air Quality Guideline:

Annual ambient air quality criterion (AAQC) = 0.3 $\mu g/m^3$.
24-hour ambient air quality criterion (AAQC) = 1.5 $\mu g/m^3$.
30-minute Interim Maximum point of impingement (Interim POI) = 450 $\mu g/m^3$.

Averaging Time To Which Guideline Applies:

See above.

Basis for Development:

Ontario MOE adopted a risk specific concentration (RsC) of 0.3 $\mu g/m^3$ as the annual AAQC based on the US EPA inhalation unit risk of 3.7E-06 per ($\mu g/m^3$), and using a 70-kg body weight adult breathing 20 m^3/day and a 1 in 1,000,000 risk level.

Ontario MOE adopted a 24-hour AAQC (1.5 $\mu g/m^3$) which was a factor of five times the annual AAQC.

The interim POI was chosen pending the outcome of consultation on a risk management framework by Ontario MOE.

Date Guideline Developed:

March 2001.

How Guideline is Used in Practice:

AAQC are used by Ontario Ministry of Environment (OME) to represent human health or environmental effect-based values not expected to cause adverse effects based on continuous exposure.

Additional Comments:

AAQC are not used by OME to permit stationary sources that emit propylene oxide to the atmosphere. The 30-minute Maximum POI is derived by mathematical scaling from an ambient air quality criterion (AAQC) and is used by OME to review permit applications for stationary sources that emit propylene oxide to the atmosphere.

Reference and Supporting Documentation:

Ontario Ministry of the Environment (Ontario MOE). 2001. Ontario Air Standards for Propylene oxide. Standards Development Branch, Ontario Ministry of the Environment. Toronto, ON. March 2001. 58 pp.

Agency: US Agency for Toxic Substances and Disease Registry (ATSDR).
Propylene Oxide Air Quality Guideline: Does not exist.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: n/a

Agency:

US Environmental Protection Agency (EPA).

Propylene Oxide Air Quality Guideline:

Reference concentration (RfC) = 30 $\mu g/m^3$.
Risk specific concentration (RsC) corresponding to 1 in 100,000 risk = 3 $\mu g/m^3$ (after rounding).

Averaging Time To Which Guideline Applies:

Continuous exposure (daily exposure over a lifetime).

Basis for Development:

The RfC was developed as follows. A two-year inhalation exposure study to rats identified a LOAEL based on extra thoracic respiratory effects at a concentration of 71 mg/m^3. A human equivalent concentration (HEC) of 2.9 mg/m^3 was adjusted with uncertainty factors (10 for protection of sensitive human subpopulations and 10 for interspecies extrapolation) to derive an RfC of 30 $\mu g/m^3$ after rounding.

The RsC corresponding to 1 in 100,000 risk (risk criteria used in Alberta) was derived in the following manner. Data from a two-year rat and mice inhalation study were used. Tumours were observed in the nasal cavity of both rats and mice at the highest dose. However, only mice showed a statistically significant increase in incidence of nasal cavity tumours over controls. An inhalation unit risk of 3.7E-06 per ($\mu g/m^3$) was calculated and used with 70-kg body weight adult breathing 20 m^3/day.

Date Guideline Developed:

RfC – last revised in 1990.
Inhalation unit risk factor – last revised in 1994.

How Guideline is Used in Practice:

The reference concentration (RfC) and inhalation unit risk are intended for use by US EPA staff in risk assessments, decision-making and regulatory activities. The risk specific concentration (RsC) is not used for any specific purposes by US EPA and is shown here to illustrate an exposure concentration in air associated with an inhalation unit risk factor derived by US EPA and a 1 in 100,000 lifetime cancer risk.

Additional Comments:

The Integrated Risk Information System (IRIS) is prepared and maintained by the US EPA. IRIS is an electronic database containing information on human health effects that may result from exposure to various chemicals in the environment.

Reference and Supporting Documentation:

US Environmental Protection Agency. Integrated Risk Information System. http://www.epa.gov/iris/ (accessed 8 August 2001).

Agency:

California Environmental Protection Agency (Cal EPA).

Propylene Oxide Air Quality Guideline:

Acute reference exposure level (REL) = 3,100 µg/m³.
Chronic reference exposure level (REL) = 30 µg/m³.
Risk specific concentration (RsC) corresponding to 1 in 100,000 risk = 3 µg/m³ (after rounding).

Averaging Time To Which Guideline Applies:

Acute REL – 1-hour averaging time.
Chronic REL – continuous exposure.
Risk specific concentration (RsC) – continuous exposure.

Basis for Development:

Nasal irritation in exposed mice was used as the critical endpoint for calculation of the acute REL. An extrapolated 1-hour exposure concentration representing a LOAEL (387 ppm) was adjusted with uncertainty factors (6 for the LOAEL, 10 for interspecies, and 10 for intraspecies) to estimate an acute REL of 3,100 µg/m³ after rounding.

The basis for the chronic REL was protection against adverse effects of the are the central/peripheral nervous systems, kidney, gastrointestinal system, liver, reproductive, and respiratory systems (CAPCOA, 1993).

The RsC corresponding to 1 in 100,000 risk (risk criteria used in Alberta) was derived as follows. Data from a two-year rat and mice inhalation study were used. Cal EPA calculated an inhalation unit risk of 3.7E-06 per (µg/m³) using the same data considered by US EPA. An inhalation unit risk of 3.7E-06 per (µg/m³) was calculated and used with 70-kg body weight adult breathing 20 m³/day.

Date Guideline Developed:

Chronic REL – 1992.
Inhalation unit risk – 1999.

How Guideline is Used in Practice:

Acute and chronic RELs are for use in facility health risk assessments conducted for the AB 2588 Air Toxics "Hot Spots" Program. The risk specific concentration (RsC) is not used for any specific purposes by Cal EPA and is shown here to illustrate an exposure concentration in air associated with an inhalation unit risk factor derived by Cal EPA and a 1 in 100,000 lifetime cancer risk.

Additional Comments:

n/a

Reference and Supporting Documentation:

California Environmental Protection Agency (Cal EPA). 1999. Determination of Acute Reference Exposure Levels for Airborne Toxicants. Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section, California Environmental Protection Agency. Oakland, CA. March 1999.

California Environmental Protection Agency (Cal EPA). 1999. Air Toxics Hot Spots Program Risk Assessment Guidelines Part II. Technical Support Document for Describing Available Cancer Potency Factors. Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section, California EPA. Oakland, CA. April 1999.

California Air Pollution Control Officers Association (CAPCOA). 1993. Air Toxics Hot Spots Program Revised 1992 Risk Assessment Guidelines. CAPCOA Toxics Committee, Cameron Park, CA. October 1993.

Agency: Louisiana Department of Environmental Quality (DEQ).
Propylene Oxide Air Quality Guideline: Ambient air standard (AAS) for toxic air pollutants = 27 $\mu g/m^3$.
Averaging Time To Which Guideline Applies: Annual average.
Basis for Development: Not stated. However, 27 $\mu g/m^3$ can be derived by using the US EPA inhalation unit risk of 3.7E-06 per ($\mu g/m^3$) and a 70-kg body weight adult breathing 20 m^3/day for a 1 in 100,000 risk level.
Date Guideline Developed: Not stated.
How Guideline is Used in Practice: AASs are used by Louisiana DEQ to review permit applications for stationary sources that emit propylene oxide to the atmosphere.
Additional Comments: n/a
Reference and Supporting Documentation: *Louisiana Administrative Code (LAC). Title 33 Environmental Quality, Part III Air, Chapter 51 Comprehensive Toxic Air Pollutant Emission Control Program. Louisiana Department of Environmental Quality. Baton Rouge, LA.*

Agency:

Michigan Department of Environmental Quality (DEQ).

Propylene Oxide Air Quality Guideline:

Initial threshold screening level (ITSL) = 30 $\mu g/m^3$ [24-hour averaging time].
Initial risk screening level (IRSL) = 0.3 $\mu g/m^3$ [annual averaging time].
Secondary risk screening level (SRSL) = 3 $\mu g/m^3$ [annual averaging time].

Averaging Time To Which Guideline Applies:

See above.

Basis for Development:

The ITSL is based on the US EPA reference concentration of 30 $\mu g/m^3$. The IRSL and SRSL are based on the US EPA inhalation unit risk of 3.7E-06 per ($\mu g/m^3$) and lifetime cancer risks of one in one million (10^{-6}) and 1 in 100,000 (10^{-5}), respectively.

Date Guideline Developed:

Not stated.

How Guideline is Used in Practice:

There are two basic requirements of Michigan air toxic rules. First, each source must apply the best available control technology for toxics (T-BACT). After the application of T-BACT, the emissions of the toxic air contaminant cannot result in a maximum ambient concentration that exceeds the applicable health based screening levels (ITSL, IRSL, or SRSL). Application of an ITSL is required for any new or modified emission source or sources for which a permit to install is requested and which emits a toxic air contaminant. The IRSL applies only to the new or modified source subject to the permit application. If an applicant cannot demonstrate that the emissions of the toxic air contaminant meet the IRSL, they may choose to demonstrate compliance with the SRSL; however, in this case they must include all sources of that toxic air contaminant emitted from the plant, not just the emission unit being permitted.

Additional Comments:

The applicable air quality screening level for chemical treated as non-carcinogens by Michigan DEQ is the ITSL. There are two health based screening levels for chemical treated as carcinogens by Michigan DEQ: the IRSL – based on an increased cancer risk of one in one million (10^{-6}), and the SRSL – based on as an increased cancer risk of 1 in 100,000 (10^{-5}).

Reference and Supporting Documentation:

Michigan Administrative Code (MAC). Air Pollution Control Rules. Part 2 Air Use Approval, R 336.1201 - 336.1299. Air Quality Division, Department of Environmental Quality. Lansing, MI.

Agency: New Hampshire Department of Environmental Services (DES).
Propylene Oxide Air Quality Guideline: 24-hour ambient air limit (AAL) = 171 µg/m³. Annual ambient air limit (AAL) = 30 µg/m³.
Averaging Time To Which Guideline Applies: See above.
Basis for Development: In the case of propylene oxide, the AALs were developed in the following manner: 24-hour Ambient Air Limit – The American Conference of Governmental Industrial Hygienists (ACGIH) 8-hour time weighted average occupational exposure limit (OEL) of 48 mg/m³ is divided by a safety factor (SF) of 100 and a time adjustment factor (TAF) of 2.8. Annual Ambient Air Limit – The reference concentration (RfC) limit established by the US Environmental Protection Agency is used as the annual AAL.
Date Guideline Developed: May 1998.
How Guideline is Used in Practice: AALs are used by New Hampshire DES to review permit applications for sources that emit propylene oxide to the atmosphere. Sources are regulated through a state-wide air permitting system and include any new, modified or existing stationary source, area source or device.
Additional Comments: n/a
Reference and Supporting Documentation: *New Hampshire Administrative Rule. Chapter Env-A 1400. Regulated Toxic Air Pollutants. New Hampshire Department of Environmental Services. Concord, NH.*

Agency: New Jersey Department of Environmental Protection (DEP).
Propylene Oxide Air Quality Guideline: Applicants are required to carry out a risk assessment in conjunction with applying for an air pollution control pre-construction permit. In the case of propylene oxide, the US Environmental Protection Agency RfC (30 $\mu g/m^3$) is used as the pollutant-specific reference concentration in which to calculate a Hazard Quotient for sources that emit propylene oxide to the atmosphere. The US EPA inhalation unit risk factor of 3.7E-06 per ($\mu g/m^3$) is used to calculate a lifetime cancer risk for sources that emit propylene oxide to the atmosphere.
Averaging Time To Which Guideline Applies: Continuous exposure (daily exposure over a lifetime).
Basis for Development: Based on US EPA Integrated Risk Information System (IRIS) data.
Date Guideline Developed: December 1994.
How Guideline is Used in Practice: Used by New Jersey DEP to review permit applications for sources that emit propylene oxide to the atmosphere.
Additional Comments: n/a
Reference and Supporting Documentation: *New Jersey Administrative Code (NJAC). Title 7, Chapter 27, Subchapter 8. Permits and Certificates for Minor Facilities (and Major Facilities without an Operating Permit). New Jersey Department of Environmental Protection. Trenton, NJ.* New Jersey Department of Environmental Protection. 1994. Technical Manual 1003. Guidance on Preparing a Risk Assessment for Air Contaminant Emissions. Air Quality Permitting Program, Bureau of Air Quality Evaluation, New Jersey Department of Environmental Protection. Trenton, NJ. Revised December 1994.

Agency: North Carolina Department of Environment and Natural Resources (ENR).
Propylene Oxide Air Quality Guideline: Does not exist.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: *North Carolina Administrative Code (NCAC). North Carolina Air Quality Rules 15A NCAC 2D.1100 – Air Pollution Control Requirements (Control of Toxic Air Pollutants). North Carolina Department of Environment and Natural Resources. Raleigh, NC.* *North Carolina Administrative Code (NCAC). North Carolina Air Quality Rules,15A NCAC 2Q.0700 – Air Quality Permit Procedures (Toxic Air Pollutant Procedures). North Carolina Department of Environment and Natural Resources. Raleigh, NC.*

Agency: Ohio Environmental Protection Agency (EPA).
Propylene Oxide Air Quality Guideline: For chemicals treated as carcinogens – like propylene oxide – applicants are required to carry out a risk assessment in conjunction with applying for a permit to determine the probability of incidence of a health effect(s) as a consequence of the new emission using US EPA unit risk values. In the case of propylene oxide, the US EPA inhalation unit risk factor of 3.7E-06 per ($\mu g/m^3$) is used to calculate a lifetime cancer risk. Risk specific concentration (RsC) corresponding to 1 in 100,000 risk = 3 $\mu g/m^3$ (after rounding).
Averaging Time To Which Guideline Applies: Continuous exposure (daily exposure over a lifetime).
Basis for Development: The RsC corresponding to 1 in 100,000 risk (risk criteria used in Alberta) was derived using the US EPA inhalation unit risk of 3.7E-06 per ($\mu g/m^3$) and a 70-kg body weight adult breathing 20 m^3/day.
Date Guideline Developed: January 1994.
How Guideline is Used in Practice: The risk specific concentration (RsC) is not used for any specific purposes by Ohio EPA and is shown here to illustrate an exposure concentration in air associated with the inhalation unit risk factor used by Ohio EPA and a 1 in 100,000 lifetime cancer risk.
Additional Comments: n/a
Reference and Supporting Documentation: Ohio Environmental Protection Agency (Ohio EPA). 1994. Review of New Sources of Air Toxic Emissions. Proposed for Public Comment. Division of Air Pollution Control, Ohio EPA. Columbus, OH. January 1994. 31 pp.

Agency: Oklahoma Department of Environmental Quality (DEQ).
Propylene Oxide Air Quality Guideline: Maximum acceptable ambient concentration (MAAC) = 480 $\mu g/m^3$.
Averaging Time To Which Guideline Applies: 24-hour averaging time.
Basis for Development: The American Conference of Governmental Industrial Hygienist (ACGIH) TLV – 8-hour time weighted average occupational exposure limit (OEL) of 48 mg/m^3 – is divided by a safety factor of 100.
Date Guideline Developed: Not stated.
How Guideline is Used in Practice: MAACs are used by Oklahoma DEQ to review permit applications for sources that emit propylene oxide to the atmosphere.
Additional Comments: n/a
Reference and Supporting Documentation: *Oklahoma Administrative Code (OAC). Title 252. Chapter 100. Air Pollution Control. 100:252-41 - Control of Emission of Hazardous and Toxic Air Contaminants. Oklahoma Department of Environmental Quality. Oklahoma City, OK.*

Agency: Rhode Island Department of Environmental Management (DEM).
Propylene Oxide Air Quality Guideline: Does not exist.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: *Rhode Island Department of Environmental Management. 1992. Air Pollution Control Regulation No 22. Division of Air and Hazardous Materials, Rhode Island Department of Environmental Management. Providence, RI. Amended 19 November 1992.*

Agency: Texas Natural Resource Conservation Commission (TRNCC).
Propylene Oxide Air Quality Guideline: Short-term effects screening level (ESL) = 210 µg/m³. Long-term effects screening level (ESL) = 21 µg/m³.
Averaging Time To Which Guideline Applies: 1-hour averaging time for short-term ESL. Annual averaging time for long-term ESL.
Basis for Development: Short-term Effects Screening Level – not stated. Long-term Effects Screening Level – not stated.
Date Guideline Developed: Not stated.
How Guideline is Used in Practice: ESLs are used to evaluate the potential for effects to occur as a result of exposure to concentrations of constituents in air. ESLs are based on data concerning health effects, odour nuisance potential, effects with respect to vegetation, and corrosion effects. They are not ambient air standards. If predicted or measured airborne levels of a chemical do not exceed the screening level, adverse health or welfare effects would not be expected to result. If ambient levels of constituents in air exceed the screening levels, it does not necessarily indicate a problem, but rather, triggers a more in-depth review.
Additional Comments: n/a
Reference and Supporting Documentation: Texas Natural Resource Conservation Commission (TNRCC) 2001. Toxicology & Risk Assessment (TARA) Section Effects Screening Levels. http://www.tnrcc.state.tx.us/permitting/tox/index.html (accessed 6 September 2001).

Agency: Vermont Agency of Natural Resources.
Propylene Oxide Air Quality Guideline: Hazardous ambient air standard (HAAS) = 0.01 $\mu g/m^3$.
Averaging Time To Which Guideline Applies: Annual average.
Basis for Development: Not stated.
Date Guideline Developed: Not stated.
How Guideline is Used in Practice: HAASs are used by Vermont ANR to review permit applications for stationary sources that emit propylene oxide to the atmosphere.
Additional Comments: n/a
Reference and Supporting Documentation: Vermont Air Pollution Control Regulations. 2001. State of Vermont Agency of Natural Resources. Air Pollution Control Division. Waterbury, VT. 29 November 2001. 187 pp.

Agency: Washington State Department of Ecology (DOE).
Propylene Oxide Air Quality Guideline: Acceptable source impact level (ASIL) = 0.27 $\mu g/m^3$.
Averaging Time To Which Guideline Applies: Annual average.
Basis for Development: The ASIL for propylene oxide is a risk-based acceptable source impact level that may cause an increased cancer risk of one in one million (10^{-6}) using US EPA's inhalation unit risk factor of 3.7E-06 per ($\mu g/m^3$) and a 70-kg body weight adult breathing 20 m^3/day.
Date Guideline Developed: September 1991.
How Guideline is Used in Practice: ASILs are used by Washington State DOE to review permit applications for sources that emit propylene oxide to the atmosphere.
Additional Comments: n/a
Reference and Supporting Documentation: *Washington Administrative Code (WAC). Chapter 173-460 WAC. Controls For New Sources Of Toxic Air Pollutants. Washington State Department of Ecology. Olympia, WA*